U.S. Coast Guard Research and Development Center
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Report No. CG-D-14-00

SUMMARY OF CUTTER ENERGY MANAGEMENT AUDIT RESULTS AND RECOMMENDATIONS

FINAL REPORT
MAY 2000

Prepared for:

U.S. Department of Transportation
United States Coast Guard
Chief of Staff
Washington, DC 20593-0001

NOTICE

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Technical Report Documentation Page

1. Report No.	2. Government Accession Number	3. Recipient's Catalog No.
CG-D-14-00		

4. Title and Subtitle	5. Report Date
SUMMARY OF CUTTER ENERGY MANAGEMENT AUDIT RESULTS AND RECOMMENDATIONS	May 2000
	6. Performing Organization Code Project No. 9207.2.1
7. Author(s) E. Diehl, W. McCarthy	8. Performing Organization Report No. R&DC-302-99
9. Performing Organization Name and Address Seaworthy Systems, Inc. 22 Main Street Centerbrook, CT 06409 U.S. Coast Guard Research and Development Center 1082 Shennecossett Road Groton, CT 06340-6096	10. Work Unit No. (TRAIS) 11. Contract or Grant No. N00033-98-D-8010
12. Sponsoring Organization Name and Address U.S. Department of Transportation United States Coast Guard Chief of Staff Washington, DC 20593-0001	13. Type of Report & Period Covered Final 14. Sponsoring Agency Code Commandant (G-CFP) U.S. Coast Guard Headquarters Washington, DC 20593-0001

15. Supplementary Notes

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16. Abstract (MAXIMUM 200 WORDS)

This report summarizes four energy audit reports conducted aboard the Reliance (210'), Juniper (225'), Famous (270') and Hamilton (378') classes of U.S. Coast Guard Cutters. Operational profiles and recent fuel consumption data for these classes in various Coast Guard Districts are presented. The report gives suggestions for reducing fuel consumption, and projects associated fuel savings for each class. Strategies common to all audited classes include use of most efficient machinery alignments, optimum transit speeds, improved pitch schedules, and reduced speed operations when feasible. Possible machinery retrofits, including lube oil heaters and reverse osmosis water-makers were also identified. Finally, the report recommends installation of permanent fuel meters, at least aboard a lead cutter in each class, and initiation of an incentive program to promote fuel efficiency and reward vessels which reduce their present fuel consumption. Realistic fuel savings of $3,334,100 per year (19%) are projected for the three WMEC and WHEC classes combined. The available operating data are too limited to project total savings for the WLB Class, but it appears that the present fuel consumption could be reduced by about 20 percent.

17. Key Words	18. Distribution Statement
energy efficiency, ships, fuel saving, machinery alignments, fuel oil meters	This document is available to the U.S. public through the National Technical Information Service, Springfield, VA 22161

19. Security Class (This Report)	20. Security Class (This Page)	21. No of Pages	22. Price
UNCLASSIFIED	UNCLASSIFIED	106	

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EXECUTIVE SUMMARY

Results and Conclusions:

Energy audits were conducted aboard a representative vessel from each of four classes of Coast Guard (CG) cutters: Reliance (WMEC 210'), Juniper (WLB 225'), Famous (WMEC 270') and Hamilton (WHEC 378'). The purpose of these audits was to establish historical baseline fuel consumption rates, and to identify strategies for future reductions. These audits included review of historical operating data, crew interviews, and onboard measurement of fuel consumption rates in various operating conditions. All audits were accomplished during routine transits, and each vessel was provided with an exit briefing, and a report summarizing key findings.

Based on the results of the underway audits, three major categories of energy saving options were identified. The first category includes operational changes which do not affect speed. The second category assumes modest speed reductions. The final category requires initial capital investments, either for retrofits or increased maintenance, but offers short payback periods and subsequent savings. While these results are specific to the classes audited, there is reason to expect that similar savings can be realized among other Coast Guard classes.

It is also recommended that a CG incentive program be established to promote energy efficiency awareness, and to reward individual vessels which realize a fuel consumption reduction from their historic average. Installation of permanent onboard fuel meters would greatly facilitate this effort. In a related project, possible retrofits to reduce cutter fuel consumption have been identified, and are being prioritized. Installation and testing of the leading candidates are anticipated.

Operational Changes While Maintaining Present Speeds:

Several instances were found where changing the machinery alignment (e.g. from dual engine operations to single engine trail shaft mode, or vice versa) could achieve the same vessel speed while reducing fuel consumption.

Pitch settings, both in single and multiple engine operations, are generally controlled by automated pitch schedules which depend on throttle position. The audits showed that some of the existing pitch schedules could be adjusted to reduce fuel consumption. The selected pitch schedule must also avoid excessive cavitation, resonant vibration, and engine torque, while maintaining sufficient revolutions per minute (rpm) to provide adequate maneuverability at low vessel speeds. However, it appeared during the audits that fuel consumption could be improved without compromising these qualities. The audits did not allow sufficient time to develop new pitch schedules for all engine alignments. Optimum pitch also depends on draft, trim, underwater surface roughness, and ambient wind and wave conditions. Thus, it is recommended that fuel meters be placed on **at least** one vessel of each class to allow underway fine-tuning of selected pitch settings. Torsion meters and a portable diesel engine analyzer would also provide useful feedback to engineering watchstanders.

Total fuel saving for the three WMEC and WHEC classes resulting from implementing these recommended operational measures 50 percent of the time without speed changes is estimated at 13.8 percent of their fuel budget, or $2,374,000 per year.

Speed Reductions:

It is well known that power requirements increase roughly as the cube of speed through the water. Thus, substantial fuel savings can be realized from relatively small reductions in operating speed. It is recognized that speed reductions would reduce the distance that could be covered in the present number of underway hours, or require increased underway hours to cover the same distances. Thus, this option is not appropriate for time-critical missions. As an example, however, a one-knot reduction in all operating speeds 50 percent of the time is considered.

Total fuel saving for the three WMEC and WHEC classes resulting from a one-knot speed reduction is estimated at 5.7 percent of their fuel budget, or $ 970,000 per year.

Upgrades/Retrofits:

Various equipment retrofits were identified, primarily the use of jacket heaters to maintain lube oil temperature when an engine is in stand-by mode, and the use of more efficient equipment for

producing steam and potable water. Other retrofits are being evaluated and will form the basis of a future report. Maintenance measures such as washing of turbocharger blades, and more frequent cleanings of hull and propeller, were also identified.

Total fuel savings for all four classes resulting from retrofits and improved maintenance was estimated at three percent of their fuel budget, or $500,000.

Total Savings:

Realistic fuel savings of $3,334,100 per year (19%) are projected for the three WMEC and WHEC classes combined. The available operating data are too limited to project total savings for the WLB Class, but it appears that the present fuel consumption could be reduced by about 20 percent.

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LIST OF ACRONYMS AND ABBREVIATIONS

1M	one engine maneuvering mode
1S	single shaft operation
1T	one engine transit mode
2M	two engine maneuvering mode
2S	two shaft operation
2T	two engine transit mode
AOPS	Abstract of Operation
A TO N	aids to navigation
BHP	brake horsepower
BRIDGE	bridge administration
CG	Coast Guard
CODOG	combined diesel or gas turbine propulsion plant
COMLANT	Command, Atlantic fleet
COMPAC	Command, Pacific fleet
D	propeller diameter
CGD01	Boston, Massachusetts district
CGD05	Portsmouth, Virginia district
CGD07	Miami, Florida district
CGD08	New Orleans, Louisiana district
CGD09	Cleveland, Ohio district
CGD11	Alameda, California district
CGD13	Seattle, Washington district
CGD14	Honolulu, Hawaii district
CGD17	Juneau, Alaska district
DOM	domestic
DOM ICE	domestic icebreaking
ELT	enforcement of laws and treaties
EMPHRS	employment hours
EtaO	propeller open water efficiency
EX	exercises
FOM	fuel oil meter
FOR	foreign
FY	fiscal year
GL	Global
GPH	gallons per hour
g/kW-hr	grams per kilowatt-hour
HQ	Headquarters
IHP	indicated horsepower
J	advance coefficient
K_Q	torque coefficient
K_T	thrust coefficient
kts.	knots (nautical miles per hour)
kW	kilowatt
kW_E	kilowatt electrical
MARPOL	International Convention for the Prevention of Pollution from Ships
MDE	main diesel engine
MEP	marine environmental protection
MIL	military
MGT	main gas turbine
MSA	marine science activities
n	shaft revolutions per minute
NAVSEA	Naval Sea Systems Command
OPS	operations
PC	personal computer
PTO	power take-off [generator]
ρ	density of water
RAD NAV	radio navigation
REC	recreational
RO	reverse osmosis
rpm	revolutions per minute
SAR	search and rescue
SEC	security
SHP	shaft horsepower
SSDG	ship service diesel generator
TRA	training
USCGC	U.S. Coast Guard Cutter
USCGR&DC	U.S. Coast Guard Research and Development Center
V	ship speed (feet per second)
w	wake fraction

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1.0 INTRODUCTION

1.1 Background

During Fiscal Years 1998 and 1999 Seaworthy Systems, Inc. was tasked by the U.S. Coast Guard Research and Development Center (USCG R&D Center) at Avery Point, Groton, CT, to conduct four underway energy management audits in the following representative WMEC 210', WLB 225', WMEC 270' and WHEC 378' Class cutters.

USCGC RESOLUTE (WMEC 620)
USCGC JUNIPER (WLB 201)
USCGC TAHOMA (WMEC 908)
USCGC SHERMAN (WHEC 720)

During the underway portion of each audit, cutter fuel rates, machinery alignments and corresponding speeds were recorded and fuel rate vs. speed curves were developed. Machinery operating practices were observed, and various fuel consumption reports, machinery logs and other related records were reviewed. Key personnel were interviewed to establish cutter missions, operating and fuel consumption profiles. From this information numerous energy efficiency techniques and strategies were developed that have been documented in detailed reports summarizing the results and conclusions derived from each audit. Copies of these reports can be obtained from the project point of contact at the USCG R&D Center, Robert Sedat, Naval Architect (860-441-2684).

1.2 Purpose and Scope

The purpose of this report is to present an overview of the energy efficiency related findings and recommendations developed from the completion of the underway audits carried out on four CG cutters. The remaining Sections of this report also discuss the applicability of these findings and recommendations to all of the cutters in each Class and, where applicable, to the entire fleet. Specifically, the following information is presented and summarized.

- Annual operating profiles.
- Annual mission profiles.
- Annual operating and mission profiles in different USCG districts.
- Estimates of total annual fuel consumption, underway and in-port.

- Projected annual fuel savings resulting from implementation of applicable energy efficiency techniques.
- Recommended energy efficiency strategies include:
    - economic machinery alignments
    - reduced speed operation
    - propeller pitch schedule modifications
    - optimum transit speeds
    - cutter/class/fleet fuel utilization, monitoring and management
    - energy efficiency monitoring instrumentation
    - machinery component operating and maintenance procedure optimization
    - hull and propeller maintenance
    - fuel curve development
    - equipment modifications and upgrades

2.0 OVERVIEW OF AUDIT RESULTS

2.1 Method and Approach

Each of the four cutter energy management audits summarized in the following paragraphs was completed on a "not-to-interfere" basis during an underway transit by two licensed, degreed marine engineers from Seaworthy under the direction of program representatives from the USCG R&D Center. The following common task elements were completed during the course of each cutter audit.

- Preparation of an audit protocol and speed curve development test agenda.
- Installation of test quality fuel oil meters.
- Pre-audit briefing of cutter crew.
- Fuel rate vs. ship speed and related data collection (e.g., fuel flows, cutter speed through the water, machinery plant parameters, etc.).
- Data analysis.
- Fuel curve development.
- Log book, machinery history, fuel use, etc., records review.
- Crew interviews.
- Preparation of a summary type debrief report presenting preliminary results and recommendations.
- Exit meeting with cognizant cutter personnel to present preliminary findings.
- Preparation and submittal of a detailed report describing the audit process and procedures and corresponding results, conclusions and recommendations.

The above listed audit task elements are generic. Actual work scopes, audit protocols and test agendas utilized in each cutter were tailored to address the machinery plant configuration and operating requirements unique to that cutter and the time available to complete each audit.

2.2 USCGC RESOLUTE (WMEC 620)

The energy management audit for USCGC RESOLUTE was carried out underway from December 1 to 3, 1998, while transiting from Norfolk, VA, to New Bedford, MA. The principle characteristics and particulars of this WMEC 210' Class cutter are summarized below:

Length Overall:	210 feet
Beam:	34 feet
Draft:	10.5 feet
Displacement:	937 tons light; 1,007 tons full load
Propulsion:	Two shafts with controllable/reversible pitch propellers (Diameter = 8.5 feet)
Engines:	Two (2) Alco 251B diesel engines (2,550 BHP, each)
Electrical:	Two (2) 250 kW Caterpillar 3406B ship's service diesel generators (SSDG)

While underway, USCGC RESOLUTE operates in either single shaft mode (60%) or two shaft mode (40%). In single shaft mode, a single main engine and one SSDG are in operation, and shaft speed and/or propeller pitch is varied to change the cutter's speed. In two shaft transit mode, both main engines are on line and one SSDG is in operation. As when in the single shaft mode, both shaft speed and propeller pitches may be varied to change the vessel's speed. Cutter speed changes are normally accomplished from the bridge control console in accordance with automated shaft rpm/propeller pitch schedules programmed in the main propulsion control system. Fuel curves derived from data captured during the speed runs are shown in Figures 2-1 and 2-2. During the runs, the cutter's mean draft was 10.96 ft, trimmed 1.08 ft by the stern, at a displacement of 1,135 tons. The cutter was not carrying a helicopter during the transit. Also, USCGC RESOLUTE's last hull cleaning prior to the energy audit occurred on September 22, 1998, with a follow-up inspection and propeller polishing on November 21, 1998, approximately two weeks prior to the audit. The fuel rates shown in Figures 2-1 and 2-2 include a combined estimated fuel consumption allowance of 11.9 gallons per hour (GPH) to account for an average underway electrical load of 180 kW, and auxiliary boiler operation to supply steam primarily for distiller operation. This was added to the measured main engine fuel consumption rates recorded

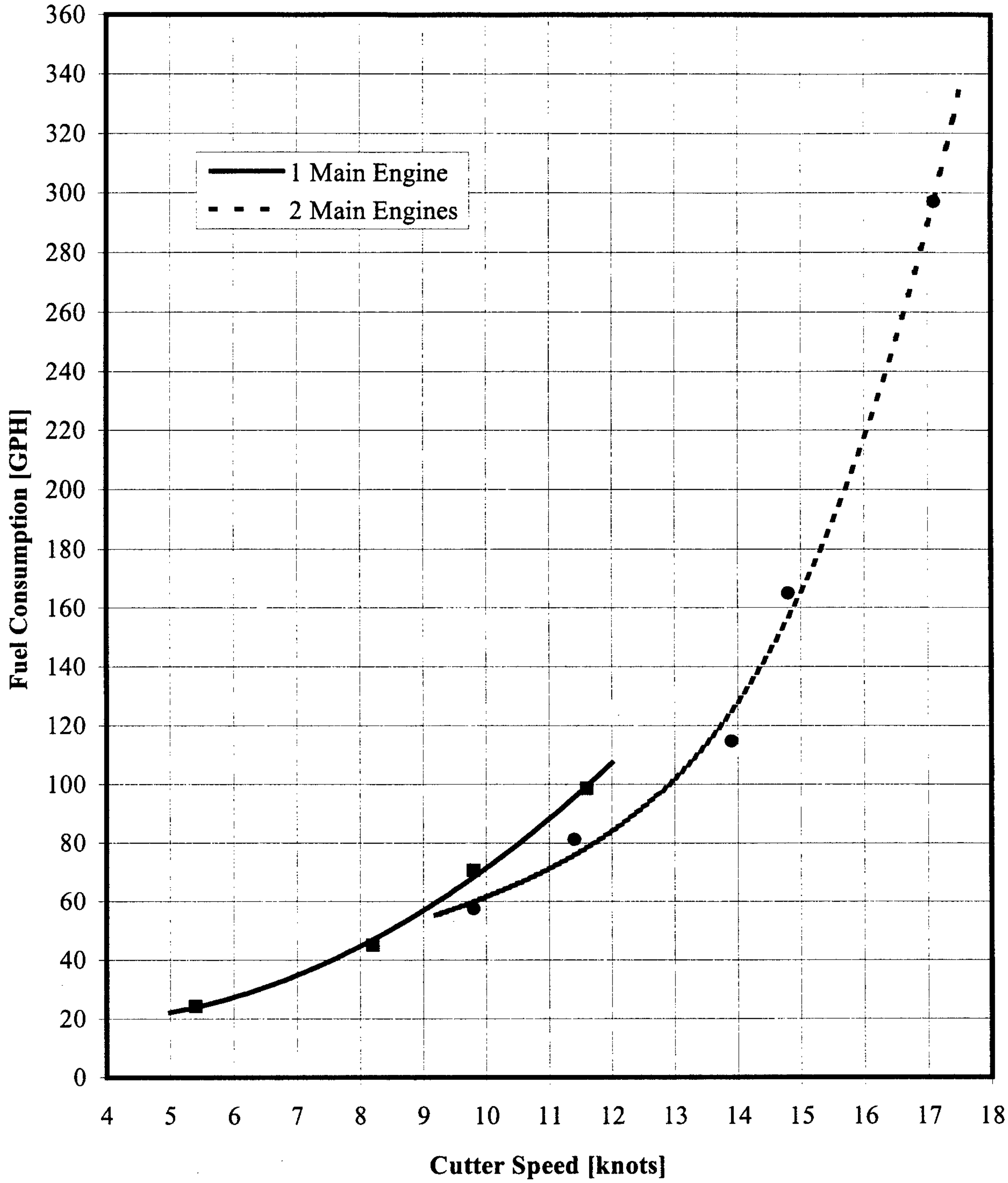

Figure 2-1. Fuel consumption versus speed (includes SSDG and auxiliary boiler fuel consumption) USCGC RESOLUTE (WMEC 620).

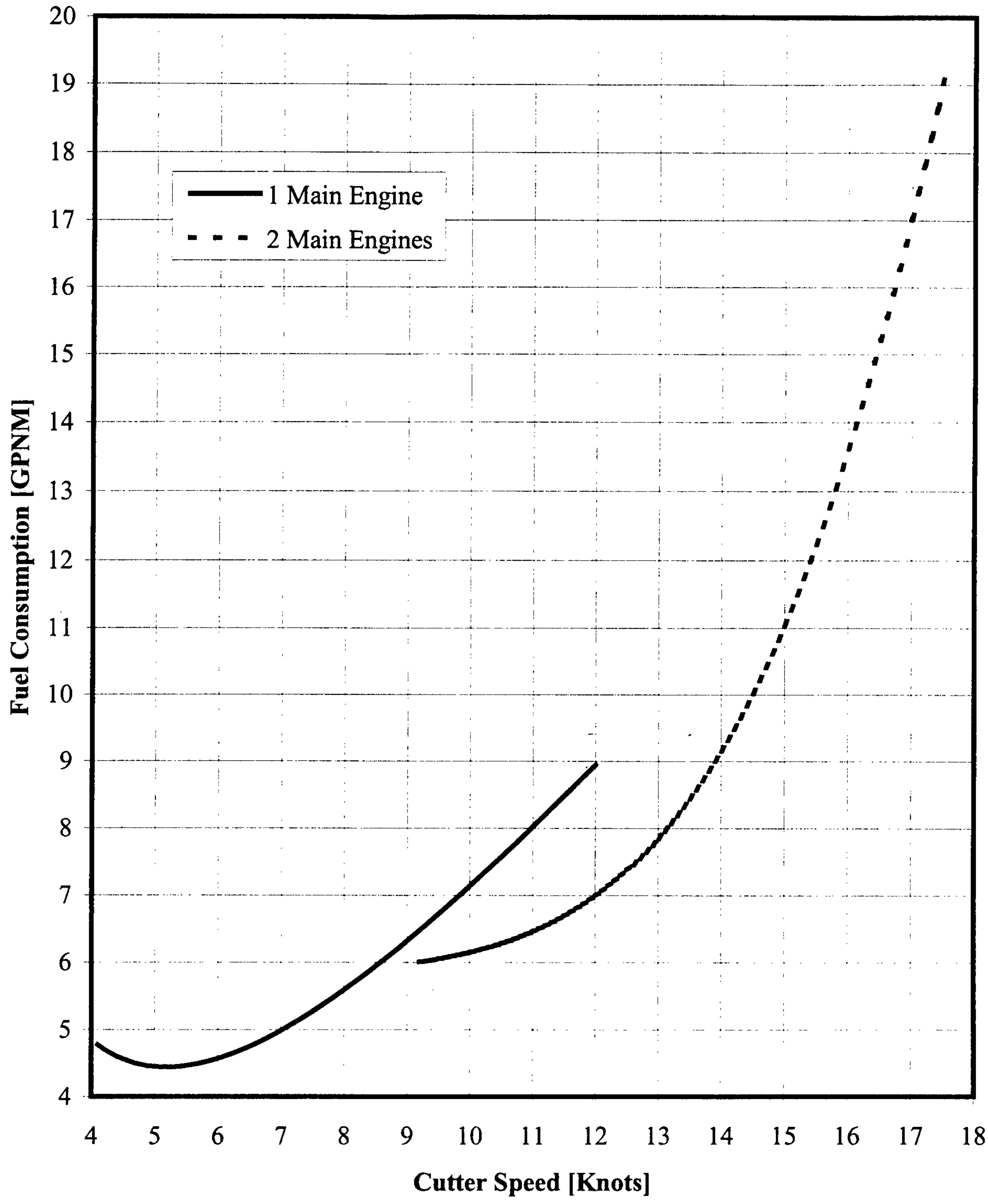

Figure 2-2. Optimum transit speed (includes SSDG and auxiliary boiler fuel consumption) USCGC RESOLUTE (WMEC 620).

during each speed run to obtain a more representative value of total cutter fuel consumption versus speed.

The following primary findings, conclusions and recommendations were developed as a result of the data and information collected and operating procedures observed during the underway audit in the RESOLUTE. (Where applicable, those sections of this report that contain a more detailed discussion and analysis of the subject matter have also been referenced.)

- The automatic propeller pitch schedule currently used for single engine/shaft operation is not optimized to provide the lowest achievable fuel consumption rates when operating in this mode. Initial tests with varying propeller pitches that were established manually as part of the audit agenda indicate that an average savings of 8.8 GPH in a speed range of 7 to 11 knots can be achieved when compared to the current single engine mode automatic pitch schedule. (Refer to Section 3.2 and Appendix B.)

- Because sufficient time was available during the transit, port and starboard main engine performance and condition were comprehensively evaluated at full power using a portable electronic engine analyzer. Various operating parameter (e.g., firing pressures, exhaust temperatures, etc.) deviations were identified that were indicative of engine component material condition degradation (e.g., valve timing, fuel injection timing, injector, nozzle spray pattern, turbocharger fouling, etc.) and corresponding observed increases in engine specific fuel rates when compared to design value. (These results are discussed in detail in the audit report for the RESOLUTE.)

- Optimum transit speeds, at which the minimum amount of fuel is consumed per nautical mile traveled, were identified as 7 and 10 knots, respectively, for single and dual engine/shaft operation when taking into account engine loading and corresponding maintenance impacts.

- Auxiliary boiler and steam system operation was reviewed and determined to be dedicated almost exclusively to supplying steam for distiller operation to produce potable water. Incorporation of an equivalently sized reverse osmosis (RO) water plant in lieu of the steam heated distiller could produce a fuel savings of approximately 35 gallons per day when underway. (Refer to Section 5.2.)

Table 2-1 presents a projection of annual underway fuel savings for the RESOLUTE achievable by operating in economic machinery alignments and/or at reduced speeds for the speed regimes, and corresponding operating hours and fuel rates are also summarized. The fuel rates shown

were taken from Figure 2-1, while the typical speeds shown below were determined based on crew interviews. The unit fuel price used to calculate annual savings was $.90 per gallon.

Table 2-1. Annual fuel savings projection for USCGC RESOLUTE (WMEC 620).

Annual Operating Profile

Speed, Knots	Machinery Alignment	Operating Hours	Gallons/Hour	Fuel Use, Gallons/Year
8	Single Shaft	1,764	45	79,380
12	Single Shaft	402	107	43,014
12	Two Shaft	670	84	56,280
16	Two Shaft	562	219	123,076
			Total:	**301,750**

Operational Change	From	To	Hours/Year	Savings, Gallons/Year	Savings, $ /Year
Alignment Change:					
Option 1	1S @ 8 kts. 8.5 ft Pitch 44.8 GPH	1S @ 8 kts. 6.5 ft Pitch 36 GPH	1,764*	15,520	13,980
Speed Change:					
Option 2	2S @ 16 kts. 219 GPH	2S @ 15 kts. 160 GPH	281**	16,580	14,920
Speed & Alignment change:					
Option 3	2S @ 12 kts. 84 GPH	1S @ 8 kts. 45 GPH	335**	13,060	11,750
Totals:				**45,160**	**$40,650**

* - Assumes each alignment change is employed 100% of the time

** - Assumes each speed change is employed 50% of the time

2.3 USCGC JUNIPER (WLB 201)

The energy management audit for USCGC JUNIPER was carried out underway from March 24 to 25, 1998, while transiting from Newport, RI to Bayonne, NJ. The principle characteristics and particulars of this WLB 225' Class cutter are summarized below:

Length Overall:	225.8 feet
Beam:	46 feet
Draft:	12.75 feet
Displacement:	2,000 tons
Propulsion:	One shaft with a controllable/reversible pitch propeller (Diameter = 10 feet)
Engines:	Two (2) Caterpillar 3608 diesel engines (3,100 BHP, each)
Electrical:	Two (2) 450 kW Caterpillar 3508B ship's service diesel generators (SSDG) and one (1) 800 kW main engine driven PTO generator

While underway, USCGC JUNIPER most frequently operates in one of three propulsion plant alignment modes: maneuvering mode (45%), one engine transit mode (20%), and two engine transit mode (35%). In maneuvering mode, both main engines are on line and both SSDGs are electrically paralleled on the main bus. Shaft speed is maintained constant at 203 rpm for proper shaft generator frequency and only propeller pitch is varied to change the ship's speed through the water. Additionally, both the bow and stern thrusters are usually in operation while in maneuvering mode. In one engine transit mode, a single main engine and one SSDG are in operation, and shaft speed and/or propeller pitch is varied to change the vessel's speed. In two engine transit mode, both main engines are on line and one SSDG is in operation. As when in the one engine transit mode, both shaft speed and propeller pitch may be varied to change the vessel's speed. In these three propulsion plant alignments, ship speed changes are normally accomplished from the bridge control console in accordance with automated shaft rpm/propeller pitch schedules programmed in the main propulsion control system.

Fuel curves derived from data captured during the speed runs are shown in Figures 2-3 and 2-4. During the runs, the cutter's mean draft was 12.75 ft, trimmed 0.5 ft by the stern, at a displacement of 1,950 tons. The USCGC JUNIPER's last hull cleaning and drydocking prior to the energy audit occurred in December 1998, five months prior to the audit. The fuel rates shown in Figures 2-3 and 2-4 include a single SSDG estimated fuel consumption allowance of 17.6 GPH to account for an average underway electrical load of 220 kW. This was added to the measured main engine fuel consumption rates recorded during each speed run to obtain a more representative value of total cutter fuel consumption versus speed. A fuel consumption of 21.9 GPH was added to the maneuvering mode fuel curves as two generators operated in parallel in this configuration.

The following primary findings, conclusions and recommendations were developed as a result of the data and information collected and operating procedures observed during the underway audit in the JUNIPER. Where applicable, those sections of this report that contain a more detailed discussion and analysis of the subject matter have also been referenced.

- The automatic propeller pitch schedule for single engine operation is not optimized to provide the lowest achievable fuel consumption rates when operating in this mode but was most likely created with the intention of avoiding excessive exhaust temperatures. For example, initial tests with varying propeller pitches that were established manually as part of the audit agenda indicate that a savings of 6.0 GPH can be achieved operating at 70% pitch and a speed of 12.0 knots when compared to the current single engine mode automatic pitch (63%) schedule. (Refer to Section 3.2 and Appendix B.)

- Optimum transit speeds, at which the minimum amount of fuel is consumed per nautical mile traveled, were identified as 7 and 9 knots, respectively, for single and dual engine operation when taking into account engine loading and corresponding maintenance impacts.

- Currently, only a dual engine automatic maneuvering mode with both SSDGs operating in parallel is used when handling buoys in order to provide redundancy in case one main engine fails. According to the ship's force, there are some instances when USCGC JUNIPER is tending buoys in open waters in low traffic areas. At these times, it is possible for the cutter to work buoys with only one main engine in service, with the other main engine placed in a secured, standby status. Fuel savings of approximately 20 GPH at all ship speeds up to 10 knots could be achieved by employing this alternative maneuvering mode.

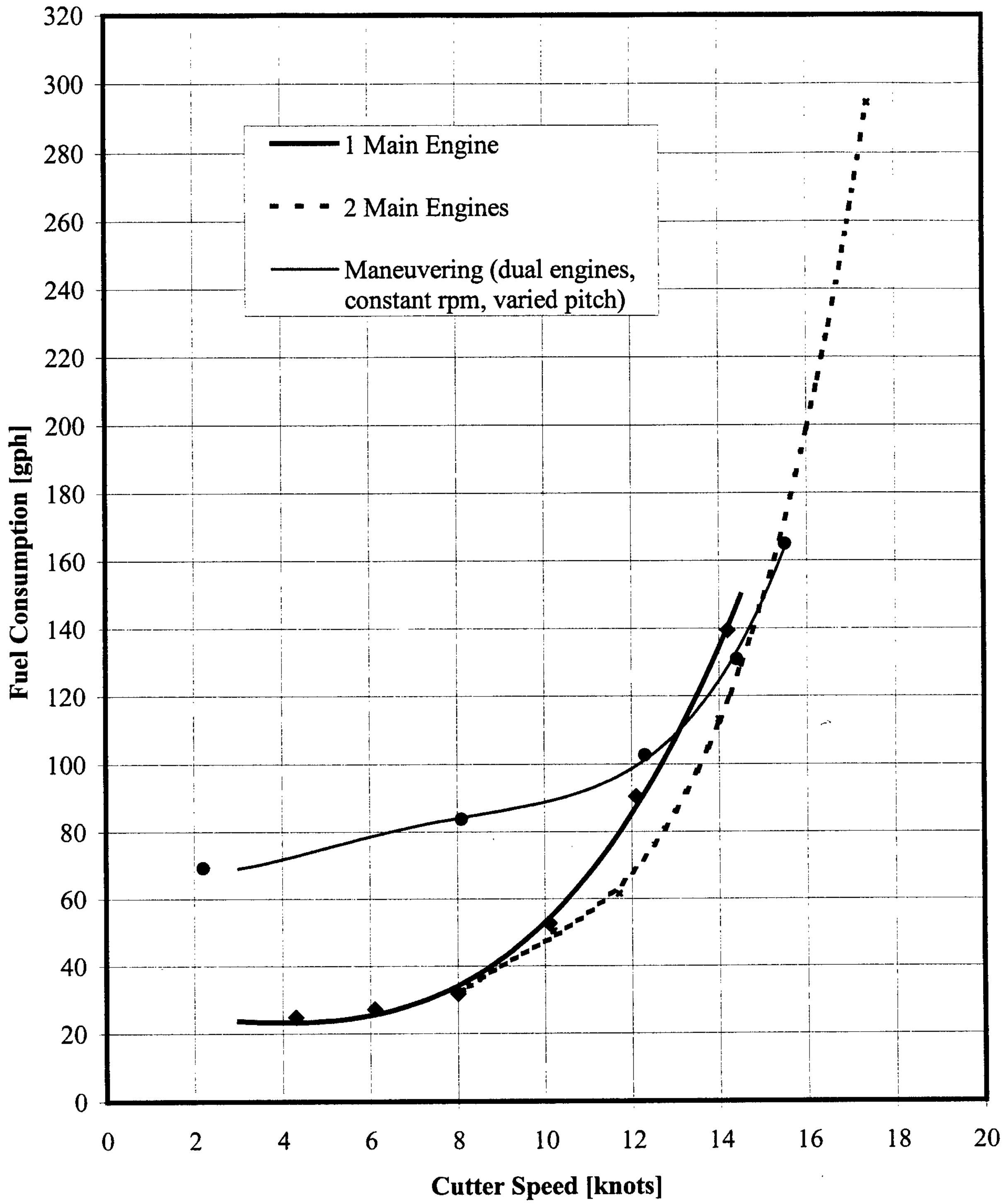

Figure 2-3. Fuel consumption versus speed (includes SSDG fuel consumption) USCGC JUNIPER (WLB 201).

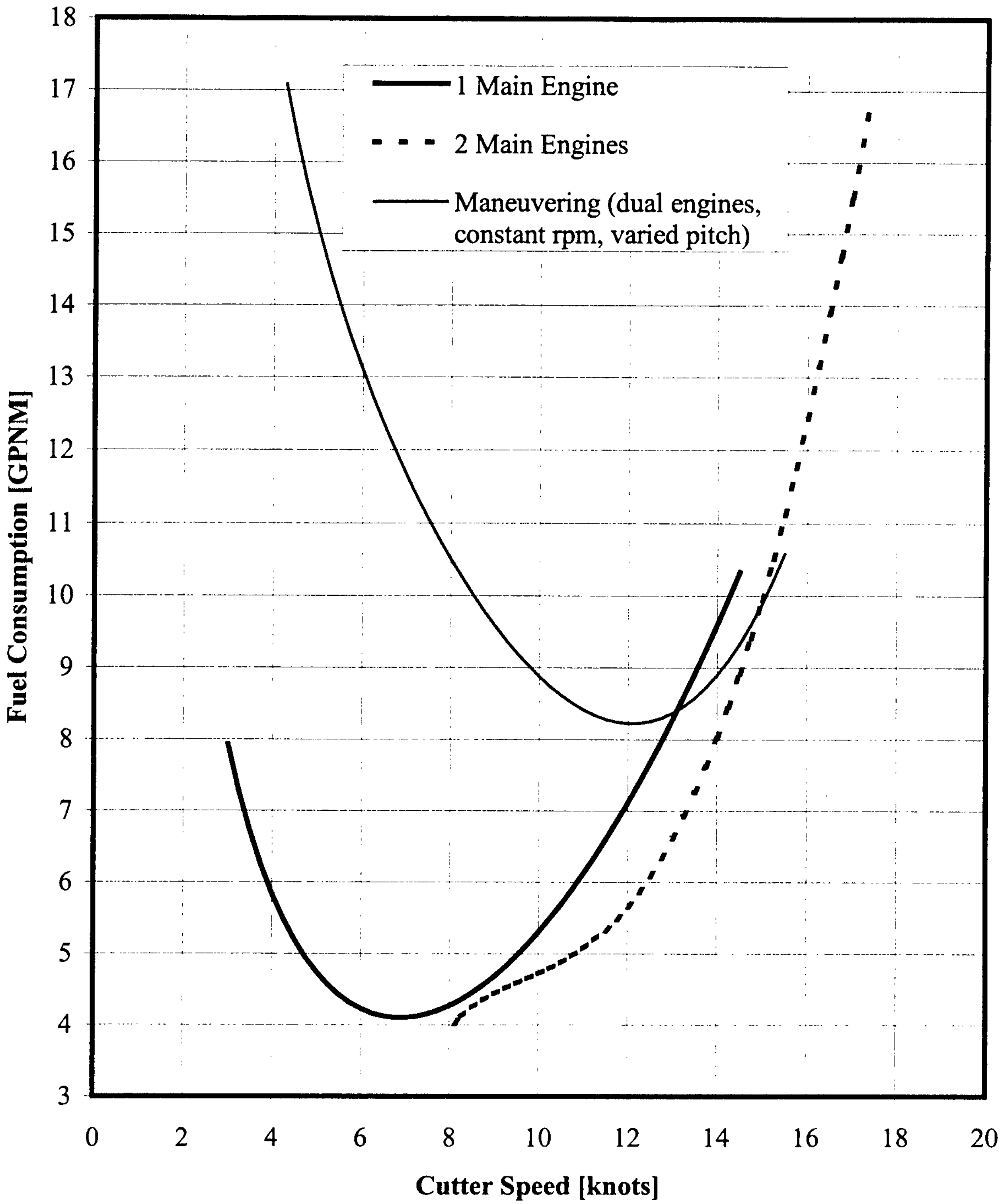

Figure 2-4. Optimum transit speed (includes SSDG fuel consumption) USCGC JUNIPER (WLB 201).

Table 2-2 presents a projection of annual underway fuel savings for the JUNIPER achievable by operating in economic machinery alignments and/or at reduced speeds for the speed regimes and corresponding operating hours and fuel rates are also summarized. The fuel rates shown were taken from Figure 2-3, while the typical underway speeds presented below were determined based on crew interviews. The unit fuel price used to calculate annual savings was $.90 per gallon.

Table 2-2. Annual fuel savings projection for USCGC JUNIPER (WLB 201).

Annual Operating Profile

Speed, Knots	**Machinery Alignment**	**Operating Hours**	**Gallons/Hour**	**Fuel Use, Gallons/Year**
4	Two Engine Maneuvering Mode (2M)	878	70	61,460
12	One Engine Transit Mode (1T)	390	85.2	33,230
12	Two Engine Transit Mode (2T)	195	66.7	13,010
15	Two Engine Transit Mode (2T)	488	148.5	72,470
			Total:	**180,160**

Operational Change	**From**	**To**	**Hours/Year**	**Savings, Gallons/Year**	**Savings, $ /Year**
Alignment Change:					
Option 1	1T @ 12 kts. 85.2 GPH	2T @ 12 kts. 66.7 GPH	390*	7,220	6,500
Option 2	2M ~70 GPH	1M ~50 GPH	878*	17,560	15,800
Speed Change:					
Option 3	2T @ 15 kts. 148.5 GPH	2T @ 12 kts. 66.7 GPH	244**	19,960	17,960
Option 4	2T @ 12 kts. 66.7 GPH	2T @ 10 kts. 47.5 GPH	98**	1,880	1,690
Totals:				**46,620**	**41,950**

* - Assumes each alignment change is employed 100% of the time

** - Assumes each speed change is employed 50% of the time

2.4 USCGC TAHOMA (WMEC 908)

The energy management audit for USCGC TAHOMA was carried out underway from April 16 to 18, 1998, while transiting from Norfolk, VA, to New Bedford, MA. The principle characteristics and particulars of this WMEC 270' Class cutter are summarized below:

Length Overall:	270 feet
Beam:	38 feet
Draft:	14 feet
Displacement:	1,200 tons light; 1,820 tons full load
Propulsion:	Two shafts with controllable/reversible pitch propellers
Engines:	Two (2) Alco 251F diesel engines (3,650 BHP, each)
Electrical:	Two (2) 600 kW Caterpillar D398 ship's service diesel generators (SSDG)

While underway, USCGC TAHOMA operates in either single shaft mode (40%) or two shaft mode (60%). In single shaft mode, a single main engine and one SSDG are in operation, and shaft speed and/or propeller pitch is varied to change the cutter's speed. In two shaft transit mode, both main engines are on line and one SSDG is in operation. As when in the single shaft mode, both shaft speed and propeller pitches may be varied to change the vessel's speed. Cutter speed changes are normally accomplished from the bridge control console in accordance with automated shaft rpm/propeller pitch schedules programmed in the main propulsion control system. Fuel curves derived from data captured during the speed runs are shown in Figures 2-5 and 2-6. During the runs, the cutter's mean draft was 13.8 ft, trimmed 0.24 ft by the stern, at a displacement of 1,812 tons. The cutter was not carrying a helicopter during the transit. The USCGC TAHOMA's last drydocking and hull cleaning prior to the energy audit occurred in September 1995, approximately 31 months prior to the audit. The fuel rates shown in Figures 2-5 and 2-6 include an estimated fuel consumption allowance of 27.5 gallons per hour (GPH) to account for an average underway electrical load of 330 kW with one SSDG on line. This was added to the measured main engine fuel consumption rates recorded during each speed run to obtain a more representative value of total cutter fuel consumption versus speed.

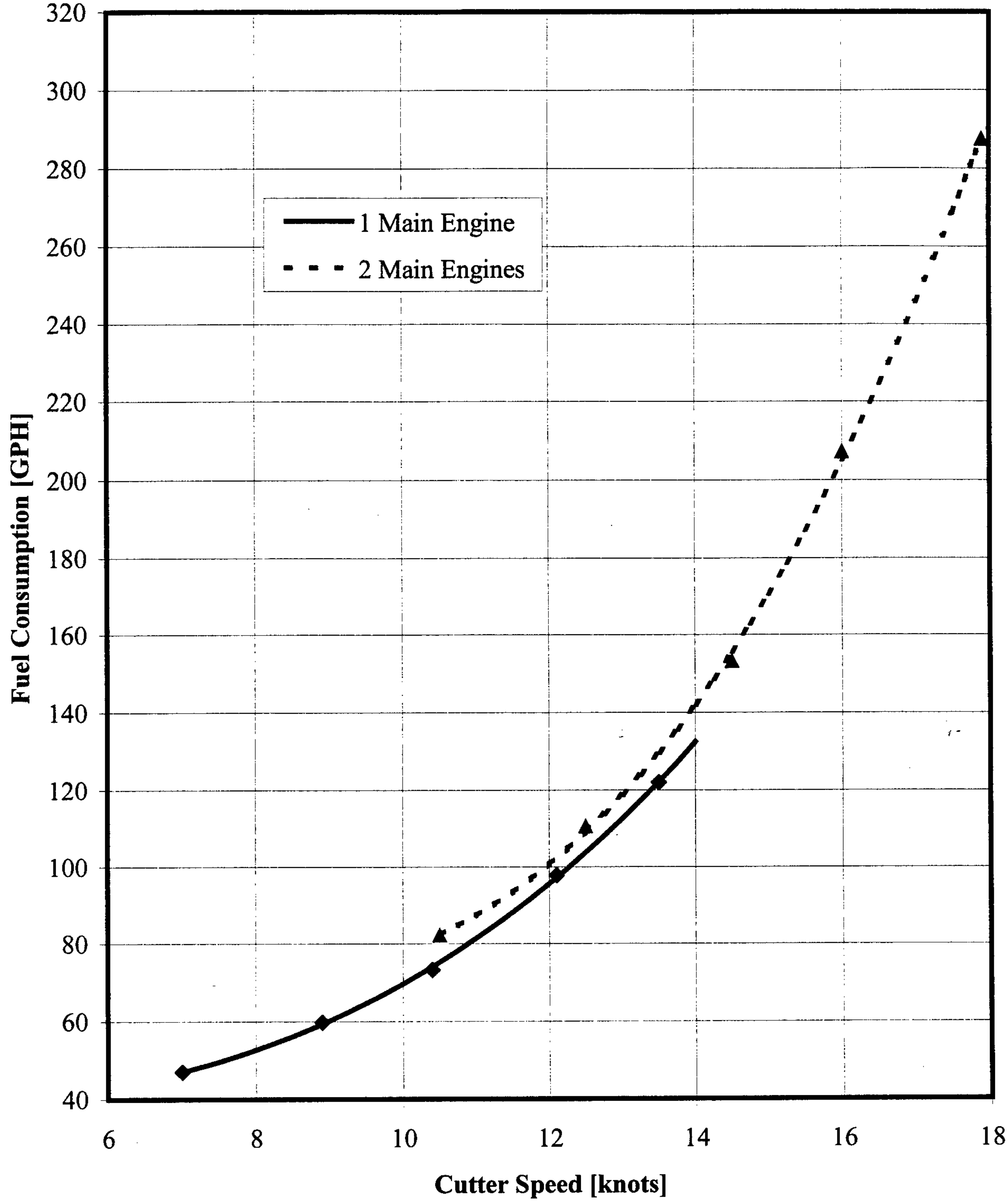

Figure 2-5. Fuel consumption versus speed (includes SSDG fuel consumption) USCGC TAHOMA (WMEC 908).

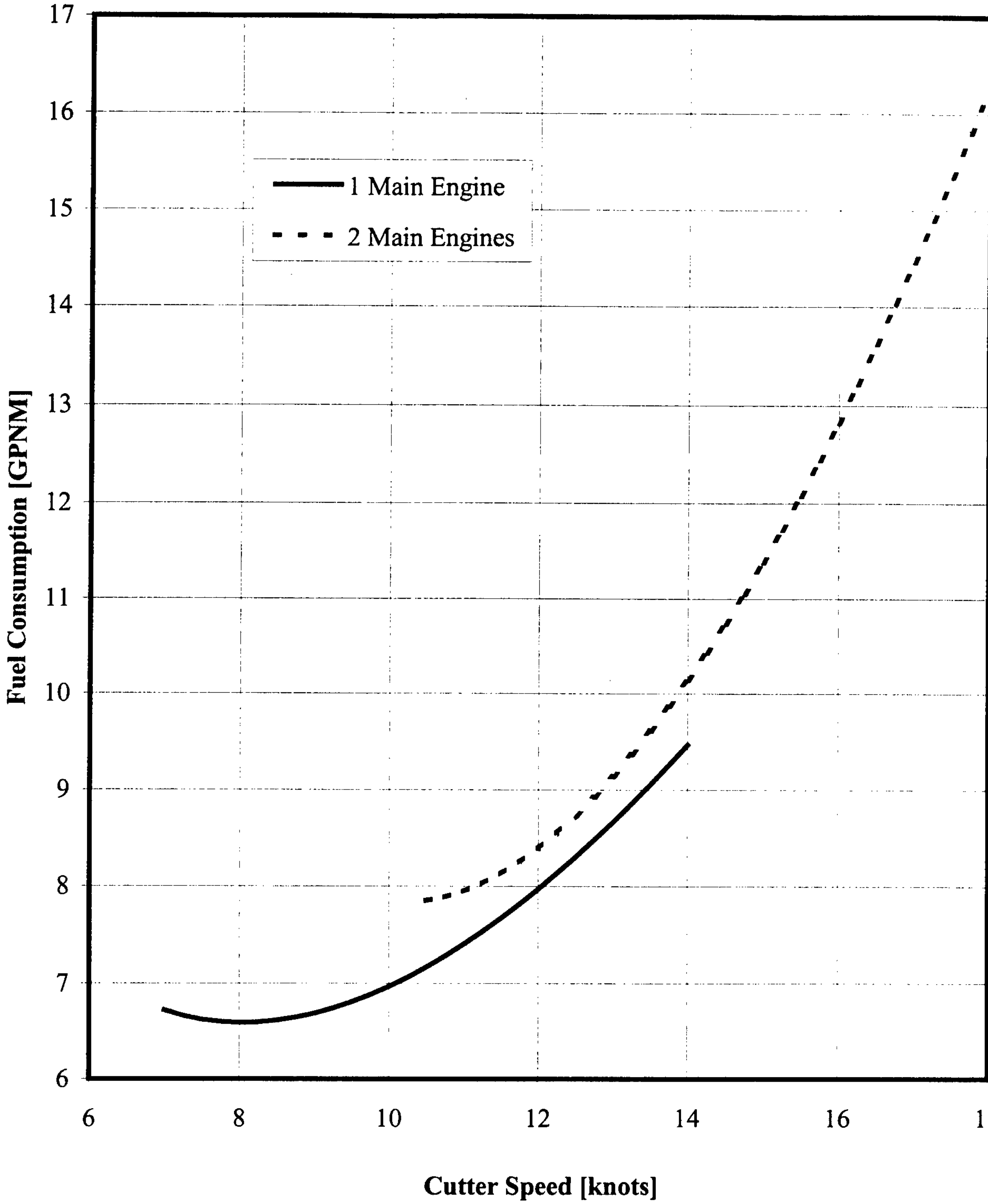

Figure 2-6. Optimum transit speed (includes SSDG fuel consumption) USCGC TAHOMA (WMEC 908).

The following primary findings, conclusions and recommendations were developed as a result of the data and information collected and operating procedures observed during the underway audit in the TAHOMA. (Where applicable, those sections of this report that contain a more detailed discussion and analysis of the subject matter have also been referenced.)

- Weather conditions and limited shaft control time during the audit prevented the collection of representative fuel flow vs. speed data that could be used to identify other more efficient single engine/shaft mode pitch settings. Also, it appears from the curves plotted on Figure 2-5 that the current single engine/shaft automatic pitch schedule has been reasonably optimized. However, single engine/shaft pitch optimization speed runs, should be carried out in the TAHOMA in smooth water at similar draft and trim conditions to determine if significant potential fuel savings will accrue from further optimization of the propulsion control system for this operating mode.

- Optimum transit speeds, at which the minimum amount of fuel is consumed per nautical mile traveled, were identified as 8 and 12 knots, respectively, for single and dual engine/shaft operation when also taking into account engine loading and corresponding maintenance impacts.

- Presently, during single engine/shaft operations the stand-by engine is started and operated in an idle condition for 15 minutes per hour to ensure that its lube oil temperature is sufficiently warm to allow for immediate operation and loading of the engine in the case of an emergency or a rapid change in required mission operating tempo. This procedure unnecessarily consumes fuel and increases engine operating hours and maintenance. A stand-by engine lube oil heating system, if installed, would eliminate the need for intermittent operation of the stand-by engine. (Refer to Section 5.2.)

Table 2-3 presents a projection of annual underway fuel savings for the TAHOMA achievable by operating in economic machinery alignments and/or at reduced speeds for the speed regimes, and corresponding operating hours and fuel rates are also summarized. The fuel rates shown were taken from Figure 2-5, while the typical underway speeds presented below were determined based on crew interviews. The unit fuel price used to calculate annual savings was $.90 per gallon.

Table 2-3. Annual fuel savings projection for USCGC TAHOMA (WMEC 908).

Annual Operating Profile

Speed, Knots	**Machinery Alignment**	**Operating Hours**	**Gallons/Hour**	**Fuel Use, Gallons/Year**
8	Single Shaft	654	52.8	34,530
10	Single Shaft	823	70	57,610
12	Two Shaft	823	100.8	82,960
14	Two Shaft	1,035	142.8	147,800
17	Two Shaft	409	243.1	99,430
			Total:	**422,330**

Operational Change	**From**	**To**	**Hours/Year**	**Savings, Gallons/Year**	**Savings, $ /Year**
Alignment Change:					
Option 1	2S @ 12 kts. 100.8 GPH	1S @ 12 kts. 96 GPH	823*	3,960	3,560
Speed Change:					
Option 2	2S @ 17 kts. 243.1 GPH	2S @ 16 kts. 204.8 GPH	205**	7,850	7,060
Option 3	2S @ 14 kts. 142.8 GPH	2S @ 13 kts. 119.6 GPH	518**	12,020	10,820
Option 4	1S @ 10 kts. 70 GPH	1S @ 8 kts. 52.8 GPH	412**	7,090	6,380
Totals:				**30,920**	**27,820**

* - Assumes each alignment change is employed 100% of the time

** - Assumes each speed change is employed 50% of the time

2.5 USCGC SHERMAN (WHEC 720)

The energy management audit for USCGC SHERMAN was carried out underway from January 4 to 6, 1999, while transiting from Alameda to San Diego, CA. The principle characteristics and particulars of this WHEC 378' Class cutter are summarized below:

Length Overall:	378.8 feet
Beam:	42.8 feet
Draft:	20.3 feet
Displacement:	2,716 Tons standard, 3,050 Tons full load
Propulsion:	Two shafts with controllable/reversible pitch propellers (Diameter = 13 feet)
Engines:	Two (2) Pratt & Whitney FT4A-6 gas turbines (14,000 BHP, each) Two (2) Fairbanks Morse 38TD8 1/8 diesel (3,600 BHP, each)
Electrical:	Two (2) 550 kW EMD 8-645E6 ship's service diesel generators (SSDG)

While underway, USCGC SHERMAN operates in either single shaft mode (67%) or two shaft mode (33%) in a combined diesel or gas turbine (CODOG) arrangement. (COGARD MLC PAC VR Fleet Advisory P011700Z MAY 98 recommends avoiding main diesel engine/main gas turbine, MDE/MGT, split plant operation.) In single shaft mode, a single MDE or MGT and one SSDG are in operation, and shaft speed and/or propeller pitch is varied to change cutter speed. In two shaft mode, two MDEs or two MGTs are on line and one SSDG is in operation. As when in the single shaft mode, both shaft speeds and propeller pitches may be varied to change the cutter speed. Cutter speed changes are accomplished from the engine control console. Under normal operating conditions, speed changes can be made in command mode in accordance with automated shaft rpm/propeller pitch schedules programmed in the main propulsion control system. During special evolutions, such as underway replenishments or vessel boardings, speed changes may be accomplished in check-out mode, which allows for more precise manual shaft speed and propeller pitch adjustment. In single and dual shaft MGT alignments, the SHERMAN

routinely operates in command mode, allowing for cutter speed control in accordance with the automated pitch schedule. In single and dual shaft MDE alignments, the SHERMAN typically operates in check-out mode, rather than in command mode.

Fuel curves derived from data captured during the speed runs are shown in Figures 2-7 and 2-8. During the runs, the cutter's mean draft was 15.23 ft, trimmed 0.13 ft by the stern, at a displacement of 3,296 tons. The ship was carrying a helicopter during the transit. The USCGC SHERMAN's last hull cleaning and drydocking prior to the energy audit occurred in July 1996, 31 months prior to the audit. The fuel rates shown in Figures 2-7 and 2-8 include a combined estimated fuel consumption allowance of 42.2 GPH to account for an average underway electrical load of 430 kW and auxiliary boiler operation to supply steam primarily for distiller operation. This was added to the measured main engine fuel consumption rates recorded during each speed run to obtain a more representative value of total cutter fuel consumption versus speed.

The following primary findings, conclusions and recommendations were developed as a result of the data and information collected and operating procedures observed during the underway audit on the SHERMAN. (Where applicable, those sections of this report that contain a more detailed discussion and analysis of the subject matter have also been referenced.)

- Due to time constraints, additional pitch optimization runs in single shaft and dual shaft MDE alignments were not possible. However, all MDE alignments in command mode were the better alternative for energy efficiency than arbitrary check-out mode manual adjustment of shaft speed and propeller pitch to achieve the equivalent cutter speed.

- During the transit, port and starboard MDE performance and condition were evaluated at full power. Various operating parameter (e.g., firing pressures, exhaust temperatures, etc.) deviations were identified that were indicative of engine component material condition degradation (e.g., fuel injection timing, injector, nozzle spray pattern, turbocharger fouling, etc.) and corresponding observed increases in engine specific fuel rates when compared to design values. (These results are discussed in more detail in the audit report for the SHERMAN.)

- In dual shaft MDE alignments, command and check-out mode shaft speed and pitch settings were nearly identical for all cutter speeds, except for 14 knots. At this speed in check-out mode, propeller pitch is decreased and shaft speed is increased to maintain higher engine rpm, and thereby, a higher attached lube oil pump discharge pressure. The reason for this adjustment is to prevent the standby electric lube oil pump from

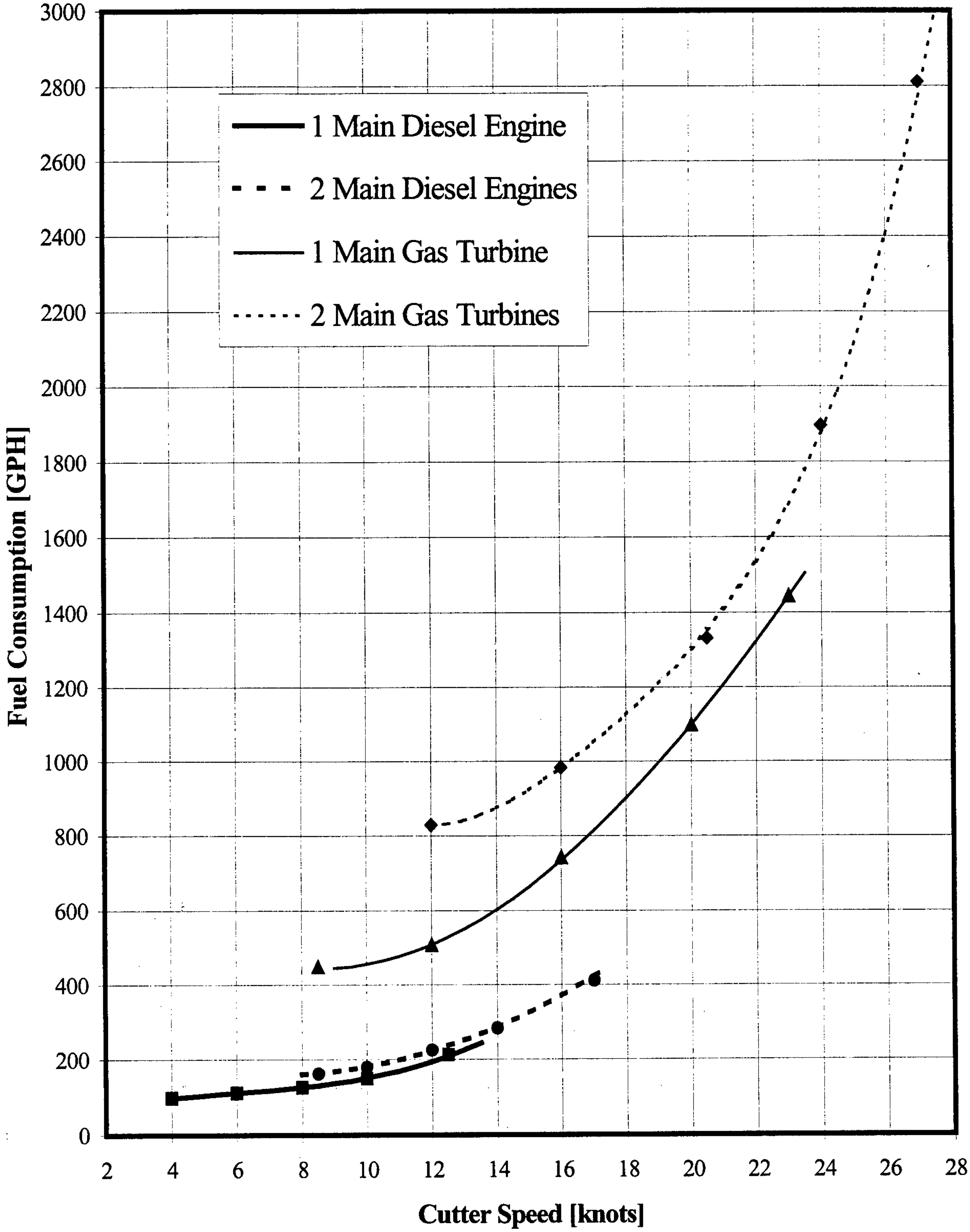

Figure 2-7. Fuel consumption versus speed (includes SSDG fuel consumption) USCGC SHERMAN (WHEC 720)

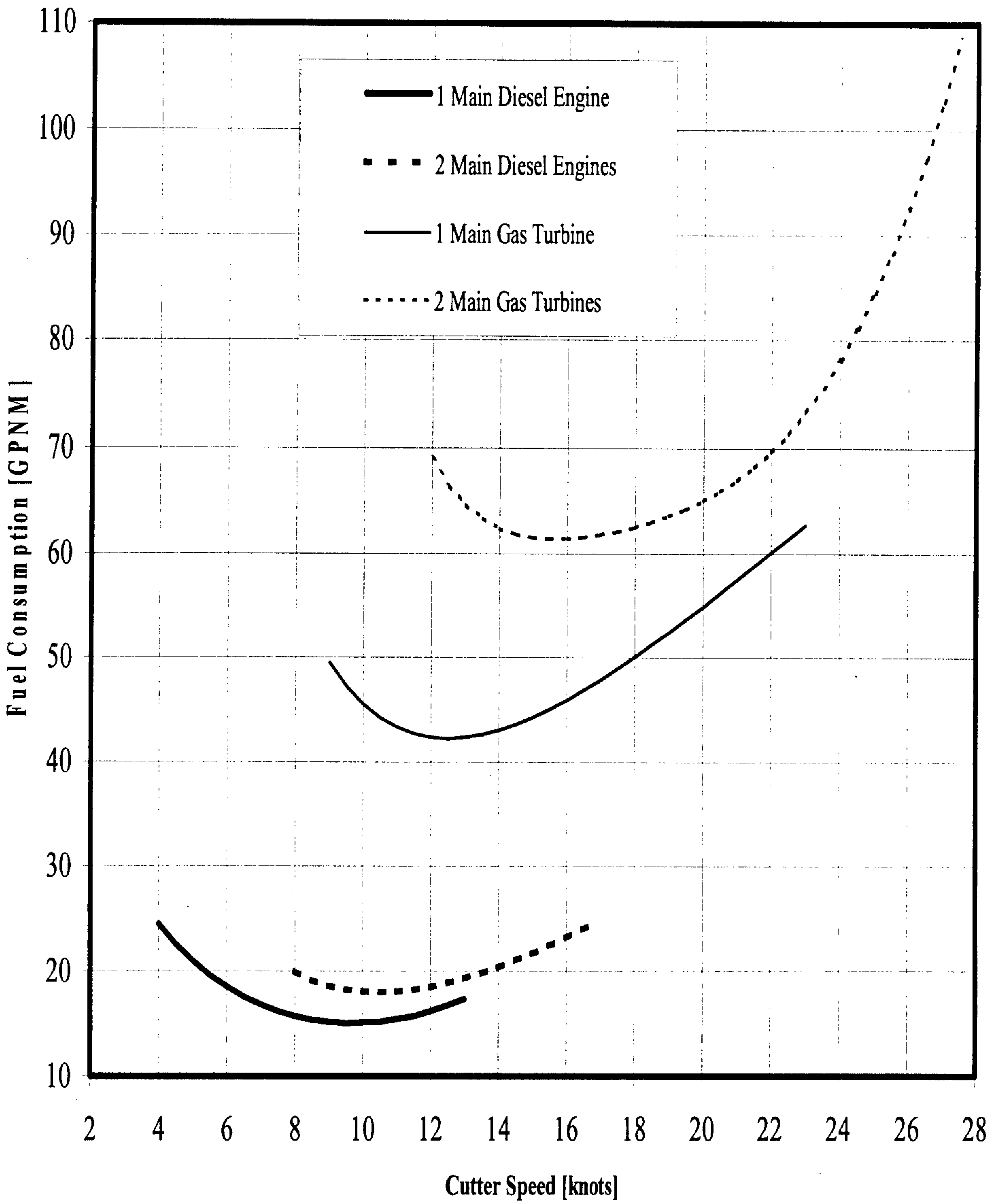

Figure 2-8. Optimum transit speed (includes SSDG fuel consumption) USCGC SHERMAN (WHEC 720).

intermittent cycling, since the attached engine lube oil pump discharge pressure at this cutter speed is approximately the same pressure as the electric lube oil pump cut-in pressure switch set point. Because a cutter speed of 14 knots is not uncommon for USCGC SHERMAN, and the increase in subsequent fuel consumption resulting from this setting is approximately 20 GPH, the electric lube oil pump cut-in pressure switch should be set to a lower pressure corresponding to less frequently utilized engine/shaft speed.

- Optimum transit speeds, speeds at which the minimum amount of fuel is consumed per nautical mile traveled, were identified as 9.5 and 12 knots, respectively, for single MDE/shaft and dual MDE/shaft operation when taking into account engine loading and corresponding maintenance impacts.

- Auxiliary boiler and steam system operation was reviewed and determined to be dedicated almost exclusively to supplying steam for distiller operation to produce potable water. Incorporation of an equivalently sized reverse osmosis (RO) water plant in lieu of the steam heated distiller could produce significant fuel savings. (Refer to Section 5.2.)

- Currently, both auxiliary boilers are operated continuously to meet steam demands in USCGC SHERMAN that can be routinely met by operating only one boiler. This operating procedure change will save fuel and significantly reduce the current boiler maintenance burdens. (Refer to Section 5.2.)

Table 2-4 presents a projection of annual underway fuel savings for the SHERMAN achievable by operating in economic machinery alignments and/or at reduced speeds for the speed regimes, and corresponding operating hours and fuel rates are also summarized. The fuel rates shown were taken from Figure 2-7, while the typical underway speeds presented below were determined based on crew interviews. The unit fuel price used to calculate annual savings was $.90 per gallon.

Table 2-4. Annual fuel savings projection for USCGC SHERMAN (WMEC 720).

Annual Operating Profile

Speed, Knots	Machinery Alignment	Operating Hours	Gallons/Hour	Fuel Use, Gallons/Year
8	One Main Diesel Engines (1MDE)	1,798	126	226,550
12	One Main Diesel Engine (1MDE)	490	200	98,000
12	Two Main Diesel Engines (2MDE)	554	210	116,340
16	Two Main Diesel Engines (2MDE)	582	368	214,180
19.8	One Main Gas Turbine (1MGT)	16	1,080	17,280
23.8	Two Main Gas Turbines (2MGT)	16	1,820	29,120
			Total:	**701,470**

Operational Change	From	To	Hours/Year	Savings, Gallons/Year	Savings, $ /Year
Alignment Change:					
Option 1	1MDE @ 8 kts. ***Check-Out Mode 142 GPH	1MDE @ 8 kts. Command Mode 126 GPH	1,798*	28,770	25,900
Option 2	2 Boiler Ops 14.0 GPH	1 Boiler Ops 11.1 GPH	1,728*	5,000	4,500
Speed Change:					
Option 3	2MDE @ 16 kts. 368 GPH	2MDE @ 14 kts. 288 GPH	291**	23,280	20,950
Speed & Alignment Change:					
Option 4	2MDE @ 16 kts. 368 GPH	1MDE @ 12 kts. 200 GPH	291**	48,890	44,000
Totals:				**105,940**	**95,350**

* - Assumes each alignment change is employed 100% of the time

** - Assumes each speed change is employed 50% of the time

*** USCGC Sherman often uses check-out mode when operating in MDE alignments

3.0 OPERATIONAL CHANGES WHILE MAINTAINING PRESENT SPEEDS

The following machinery alignment savings projections conservatively reflect the unpredictable nature of cutter operation and mission assignments by assuming that sustained underway energy efficiency opportunities will occur only 50 percent of the time. Fuel savings estimates previously discussed in Section 2.0 are specific to the cutters visited, and were calculated from operating profiles based on crew interviews. Fuel savings calculations presented in this section project average class performance using operating profiles created from five years of Abstract of Operations data and applying fuel consumption rate curves developed for RESOLUTE, JUNIPER, TAHOMA, and SHERMAN, treating each as representative of their respective class. All projected fuel savings shown in the following paragraphs are based on a unit fuel price of $0.90 per gallon.

3.1 Economic Machinery Alignments

Savings projections from implementation of economic machinery alignments were computed using the cutter class annual fuel consumption and operating profiles which are presented in Section 6.2, and by changing the "as found" machinery alignment for each mission to reflect the most efficient mode that can be employed to obtain the required speeds and corresponding lower fuel consumption rates. Applying these lower fuel rates to the time and speed profiles, which remain unchanged, lower average annual fuel consumption totals per mission and per cutter accrue. These results are tabulated for each class in Appendix A and are summarized below in Table 3-1.

Table 3-1. Economic machinery alignment fuel savings projections, per cutter.

Class	Fuel Savings, Gallons Per Year / $ Per Year
WMEC 210'	7,930/$7,140
WLB 225'	13,215/$11,890
WMEC 270'	4,105/$3,690
WHEC 378'	112,525/$101,270

3.2 Propeller Pitch Optimization

The pitch program for a controllable/reversible pitch propeller is generally developed to minimize cavitation and avoid poor combinations of rpm and torque for the engine. There is

rarely one pitch schedule that perfectly matches engine fuel efficiency with these considerations throughout the entire speed and power range. For example, tests performed on two of the audited cutters, RESOLUTE and JUNIPER, demonstrated that the single engine automated pitch schedule was not the optimum from a fuel consumption standpoint. Calculations in Appendix B show that a change in the current pitch schedule can reduce fuel consumption at 12 kts. by 22-39 percent. Testing by the ship's force or others going outside the program pitch schedules for both single and twin engine/shaft operation with various pitches and rpm's to produce the desired speed while monitoring fuel oil flow meters can be accomplished easily without jeopardizing cutter missions. New pitch programs can then be created and entered into the ship's control logic after identification of the most fuel efficient pitch/rpm combination and the resultant overall effects on the machinery plant have been determined. In some cases, the lowest fuel consuming pitch and rpm combination can cause operation in the smoking portion of an engine's power versus rpm characteristics and/or result in high exhaust temperatures and brake mean effective pressure, (bmep).

Appendix B shows that it is possible to calculate a fuel rate for a given speed through water and pitch setting, using basic model test information like resistance, wake fraction, thrust deduction, and relative rotative efficiency. These data are combined with propeller open water characteristics to determine operating rpm, torque and power. Rpm and power can then be used in conjunction with the engine fuel map to predict the specific fuel rate. In practice, however, resistance (and hull/propeller interaction effects) depend on draft, trim, hull smoothness, wind and waves. Thus, it is not possible to calculate optimal pitch schedules for all conditions. Additionally, in order to realize maximum savings from pitch optimization, a cutter must have an on-board fuel metering system similar to the one described in Section 5.1 of this report.

Both the calculated fuel savings shown in Appendix B and the data obtained from the limited pitch optimization testing conducted during the subject energy audits indicate that substantial reductions in single engine/shaft mode fuel consumption are achievable via optimization of automatic single engine pitch programs for the WLB 225' and WMEC 210' and 270' and WHEC 378' Classes. Based on these results, consideration should also be given to evaluating and

optimizing the automatic twin and single engine/shaft operating mode pitch control schedules in all other cutter classes where it is applicable. Propeller pitch schedule optimization also offers the greatest potential for achieving continuous fuel consumption reductions without modifying current cutter operating procedures and speed profiles. Table 3-2 presents the potential annual underway savings that would result from an average three percent fuel consumption reduction achieved after optimizing propeller pitch schedules for all engine operating modes in the WMEC 210', WLB 225', WMEC 270' and WHEC 378' Classes. The estimated savings of three percent is based on the observed single engine pitch optimization on JUNIPER and RESOLUTE which demonstrated an average savings of six percent across the entire tested speed range. Half of that savings is a conservative estimate for two engine operation, as no testing was performed for two engine pitch optimization. These savings projections are derived from the current average annual class per cutter underway fuel consumption totals shown in Appendix H.

Table 3-2. Propeller pitch optimization fuel savings projections, per cutter.

Class	Fuel Savings, Gallons Per Year/$ Per Year
WMEC 210'	7,500/$6,750
WLB 225'	3,900/$3,510
WMEC 270'	10,900/$9,810
WHEC 378'	25,600/$23,040

3.3 Fuel Utilization Management System

At this time there is no central cutter fuel utilization management system that allocates, monitors and projects fuel consumption requirements on a quarterly (or annual) basis for the USCG fleet. However, the required elements for such a system exist at the cutter, unit and area level where fuel consumption is tracked in terms of overall allocation and consumption on an average per day basis. (However, no distinction is currently made between fuel consumed underway and in port.) The reports listed below are presently utilized to obtain fuel consumption related data.

- Monthly unit fuel reports
- AOPS (hours underway/in port, etc.)
- Summary area report, e.g., COMLANT and COMPAC AREA COGARD AOFCs (Daily fuel consumption allocation and usage rates by cutter and class)

Information from these existing reports would form a major part of the information source and flow that is necessary for the implementation of a central, fleetwide fuel utilization management system. Additional elements and resources required to establish this system include the following:

- Establishment of an organization within the command structure that is responsible for implementation, management and monitoring the system
- Cutter level energy efficiency and operational strategy and technique training
- Fuel oil meter installation in all USCG cutters
- Development of cutter performance baselines and benchmarks to evaluate energy efficiency progress
- Adaptation/revision of current fuel consumption and operational reports to record and transmit necessary daily in port and underway fuel consumption data

To sustain energy efficiency awareness and develop motivation for cognizant personnel, an incentive/award process should also be included as a key component of the fuel utilization management system. This can include returning a portion of the dollar value of the fuel saved to the cutter to cover other operational budget short falls (e.g., maintenance and repair, etc.). Individual "smart cutter" energy efficiency cash awards, to be utilized in the same manner, can also be established to recognize the most efficient cutters on a class, area and fleet basis.

Where these systems have been implemented by the U.S. Navy, individual ship fuel consumption reductions from historic fuel consumption baselines have ranged from 3 to 16 percent. Additionally, with time, the fuel utilization data base that will be established through system implementation will become an invaluable resource for operational planning and fuel use projections and out-year fuel acquisition budget development requirements.

3.4 Other Operating Techniques and Strategies

Various common energy efficiency techniques and strategies that were recommended for USCGC RESOLUTE, JUNIPER, TAHOMA and SHERMAN are also applicable to all cutters in these classes, as well as to most other cutter types making up the USCG fleet. Taken individually these actions may not produce large, sustained fuel savings. However, if utilized in

the aggregate and applied continuously, they will produce significant fuel consumption reductions and provide other benefits such as increased cutter and machinery reliability and readiness and reduced maintenance burdens.

3.4.1 Fuel Curves

When fuel meters are installed, cutter crews can easily develop their own fuel consumption versus speed curves. The procedure for developing fuel curves is straightforward and can be accomplished while the cutter is carrying out assigned missions or transiting, without affecting either evolution. Maintaining current fuel curves helps to sustain crew awareness of energy efficiency issues at a high level and provides the ability to measure deviations in fuel consumption due to such factors as hull fouling, displacement changes, operating procedure revisions and engine maintenance. Posting fuel curves near the fuel meter displays also enables the crew to quickly visualize their current operating condition with regard to fuel consumption versus past performance and to develop, refine and implement their own fuel savings techniques.

3.4.2 Hull and Propeller Condition and Maintenance

Hull fouling can have a significant impact on fuel consumption, particularly at high vessel speeds. Naval Sea Systems Command (NAVSEA) underwater hull studies on combatants ["Waterborne Underwater Hull Cleaning of Navy Ships," NSTM S9086-CQ-STM-OOA, June 1996], have shown that moderate hull fouling across an aggregate 25 percent of the underwater hull surface area can often lead to fuel consumption increases of 15 percent or more in order to maintain a given ship speed. Periodic underwater hull and propeller inspections should be conducted to determine if surface cleaning is required, and new anti-fouling hull coatings should be considered to increase the time between necessary hull cleanings.

3.4.3 Electric Load Reduction

To achieve further savings, the ship's force must also be cognizant of energy efficiency in all areas to avoid the small losses which can add up to overall ship fuel consumption increases of from three to five percent due to unnecessary increases in cutter electrical loads. Examples of additional energy losses are: poorly maintained air-conditioned space boundaries; excessively low air conditioned space temperatures; excessive lighting in unmanned spaces; and excessive

hot water consumption. The most important aspect of conserving energy aboard ship is for "all hands" to be involved in the attempt to use less fuel. Table 3-3 below presents the fuel saved by operating the on one SSDG instead of two at the same total electrical load and the fuel savings for every 20 kW reduction of ship's service electrical load.

Table 3-3. Fuel consumption savings from electrical load reduction.

Class	Savings for Operating on One SSDG Versus Two at Same Load [GPH]	Savings from Reducing Load by 20 kW [GPH]
WMEC 210'	1.9	0.9
WLB 225'	4.3	1.2
WMEC 270'	3.6	1.5
WHEC 378'	5.3	1.8

3.4.4 Combustion Air and Fuel Oil Systems Cleanliness

Diesel engine air intake filters should be kept clean and the pressure drop across the filters should be monitored on a regular basis. The charge air cooler air side should also be cleaned at regular intervals. For a typical marine diesel engine, fuel consumption will increase by 0.5 percent for every 10°F rise in combustion air temperature at a constant power output. Engine turbochargers should be properly maintained by cleaning air and gas sides at the intervals recommended by the manufacturer or as indicated by engine operating and performance data. The temperature rise across the air side and temperature drop across the gas side of the turbocharger should be also carefully monitored. These parameters generally provide a good indication of the efficiency of the unit and can alert the operator as to when cleaning should be performed. Additionally, the exhaust back pressure at the outlet of the turbocharger should be monitored. If this pressure increases, the engine will operate inefficiently. Depending on the installation, an increase in back pressure of as little as 3" H_2O can cause a 1 percent increase in fuel consumption.

Proper fuel oil conditioning and treatment is also essential for reliable diesel engine operation and optimum performance. Because tolerances are very close for injectors/injector pumps, any foreign particulate matter in the fuel could accelerate wear or plug nozzle holes. If fuel is

contaminated by water, corrosion can also take place in these units that can ultimately lead to injection pump seizures. Fuel and lubricating oil filters and coalescers should be properly maintained and changed as required to sustain maximum water removal efficiencies. Many installations have fuel filters directly mounted on the engines. These filters should also be monitored frequently and changed when fuel oil differential pressure across the filter exceeds the manufacturer's specified maximum limit.

Gas turbines also rely on large volumes of clean combustion air for maximum efficiency. Approximately two-thirds of this air flow is used for cooling and flame centering within the combustor, while one-third is actually consumed by the combustion process. This large air flow rate, drawn from the external ocean environment, can severely tax the installed air filtration/moisture separation system. Moisture separators should be periodically cleaned to minimize air inlet pressure losses. (Blow down doors open when excessive pressure drops occur, but this allows unfiltered air to enter the engine.) Oily vapor, dirt, and sea salt ingested by a gas turbine can cause rapid deterioration of engine performance by coating compressor blades, and salt-induced corrosion can take place in the hot section of the engine. A one inch H_2O pressure drop increase across intake air or exhaust ducting systems will cause a $\approx$0.5 percent decrease in turbine power output and a $\approx$0.3 percent increased fuel consumption while maintaining a given cutter speed. Similarly, a fouled compressor section will also cause increased fuel use and higher exhaust temperatures, as every 10^{o}F increase in air temperature supplied for combustion will raise fuel consumption by $\approx$0.5 percent.

3.4.5 Machinery Monitoring and Maintenance

Monitoring plant performance, regularly inspecting machinery conditions, and reviewing logs for trends all provide the operator with information needed to operate the propulsion plant efficiently and to make necessary corrections. Regular monitoring will ensure optimum plant performance and fuel savings for all cutter speeds and machinery alignments. The material condition and maintenance of various systems, components and controls is an important factor in minimizing fuel consumption and increasing cutter readiness.

In most cutters, machinery operating parameters are recorded regularly by watch personnel on log sheets, or automatically by data logger systems. Watchstanders should be properly trained to correctly read instrumentation and record and interpret this data. A trend of degraded performance or readings outside normal values may be an indication of poor material condition, a need for maintenance, operator error, etc. Propulsion system logs and records provide a comprehensive, chronological material history of the machinery's performance, maintenance and repairs. If properly maintained and utilized, these logs and records can aid in trouble-shooting problems and assist in monitoring trends, as well as provide necessary information for maintenance planning.

Daily fuel use logs and fuel and water reports also provide a continuous means to monitor fuel and water consumption. These logs document fuel consumption and provide feed back data for supervisory personnel to use in evaluating overall plant performance. Used in conjunction with fuel oil flow meters and fuel curves, a complete picture of the energy consumed can be obtained.

Engine performance should be monitored frequently to ensure that its material condition and readiness remain at a high level. Engine readings (temperatures and pressures) should be logged regularly and determined to be within normal operating limits. Parameters falling outside of these limits should be investigated and corrective actions taken before a malfunction and/or impending failure occur.

Two relatively straightforward indications of diesel engine performance and condition are cylinder compression pressure and cylinder exhaust temperature. The observed deviation in compression pressure between any two cylinders should not exceed manufacturer's specifications. To ensure balanced loading of all engine cylinders, exhaust temperatures should also be monitored. Generally, cylinder exhaust temperatures should not vary by more than 100°F, cylinder to cylinder and/or bank to bank, for in-line applications or naturally aspirated engines. Turbocharged engine cylinder exhaust temperatures should not differ by more than 150°F. Temperature imbalances exceeding these limits should be investigated and corrected. Additionally, these two parameters provide a generalized indication of the engine's material

condition while it is in operation. Conditions such as improper valve/injector timing, fouled or worn injectors, leaky exhaust valves, worn rings, improper rack settings, etc., can cause pressure and temperature imbalances between cylinders, while overall high cylinder temperatures are an indication of an overloaded engine. On larger engines fitted with air cocks, a more detailed evaluation of cylinder to cylinder engine performance and condition can be obtained from manually drawn indicator cards or from a portable electronic diesel engine analyzer, as described in Paragraph 5.1.2.

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4.0 CUTTER SPEED REDUCTION

Since fuel consumption varies roughly as speed cubed, small speed changes can result in significant changes in fuel consumption. Thus, an additional incremental savings will also accrue when operating in the economic machinery alignments discussed above from reducing speed by one (1) knot in all speed regimes across all mission categories. Appendix C tabulates the impact of this speed change on annual per cutter mission and total fuel consumption. These results are summarized in Table 4-1. (Note also that Tables in Appendix C show only the savings due to a one knot speed reduction when in economic machinery alignments, while the tables in Appendix A show the savings due to economic machinery alignments, only.)

Table 4-1. Fuel saving projections per cutter due to one knot speed reduction (50% of operating hours.)

Class	Fuel Savings, Gallons Per Year / $ Per Year
WMEC 210'	27,200/$24,480
WLB 225'	11,550/$10,400
WMEC 270'	25,550/$23,000
WHEC 378'	28,200/$25,380

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5.0 UPGRADES AND RETROFITS

The following paragraphs discuss and describe other energy efficiency-oriented operating procedures and maintenance practices that when implemented, will produce additional fuel consumption reductions. Instrumentation and equipment additions, modifications or upgrades that will result, directly or indirectly, in additional incremental underway fuel savings are also described below. For the most part, these items were identified during the underway audits completed on USCGCs RESOLUTE, JUNIPER, TAHOMA and SHERMAN. Where appropriate, estimates of implementation costs for and the expected savings that will accrue from incorporation of these procedures and equipment modifications and additions have also been provided, along with their applicability to individual cutters, classes or the entire fleet.

5.1 Energy Efficiency Monitoring Instrumentation

5.1.1 Fuel Oil Meters

Cutter crews are willing and quite capable of making operational changes to minimize fuel consumption. However, to do this efficiently they need to observe the results of these changes. Fuel oil meters (FOM) are an essential tool for reducing shipboard fuel consumption because they give the operator the ability to immediately measure plant adjustment results, account for total fuel consumption and develop cutter fuel curves. Without a precise, repeatable method to measure fuel consumption rates, it is difficult, if not impossible, to accurately quantify any fuel savings obtained through the implementation of most energy efficiency strategies and techniques.

Figure 5-1 shows a typical arrangement of supply and return FOMs for a typical diesel engine installation. The meters shown in this figure are Hoffer SY-100 turbine types that were designed and tested to military specifications, including shock and vibration. A typical two-engine ship-set of these fuel oil meters, including: display units (which would also compute the difference between the supply and return flows for each engine); flow straightening piping (ten inches before the meter and five inches after the meter); and connectors would cost $12,200 to acquire. Installation is estimated at approximately $2000 per cutter, depending on the amount of piping system modifications required and additional features added (e.g., by-pass valves, accumulators,

pressure, gages, etc.). (Appendix D contains a FOM price quote from Hoffer, along with additional product information.) This cost estimate is based on purchasing and installing ¾" supply meters and ½" return meters that would be suitable for the WMEC 210', WLB 225', WMEC 270', and WHEC 378' Classes which have two diesel engines and fuel flow ranges that match the turn-down of the Hoffer SY-100 FOMs. Before meters are purchased, the effects of increased fuel system pressure drop resulting from FOM installation should also be determined. In some cases, the size of the meters may need to be increased to minimize this added flow resistance.

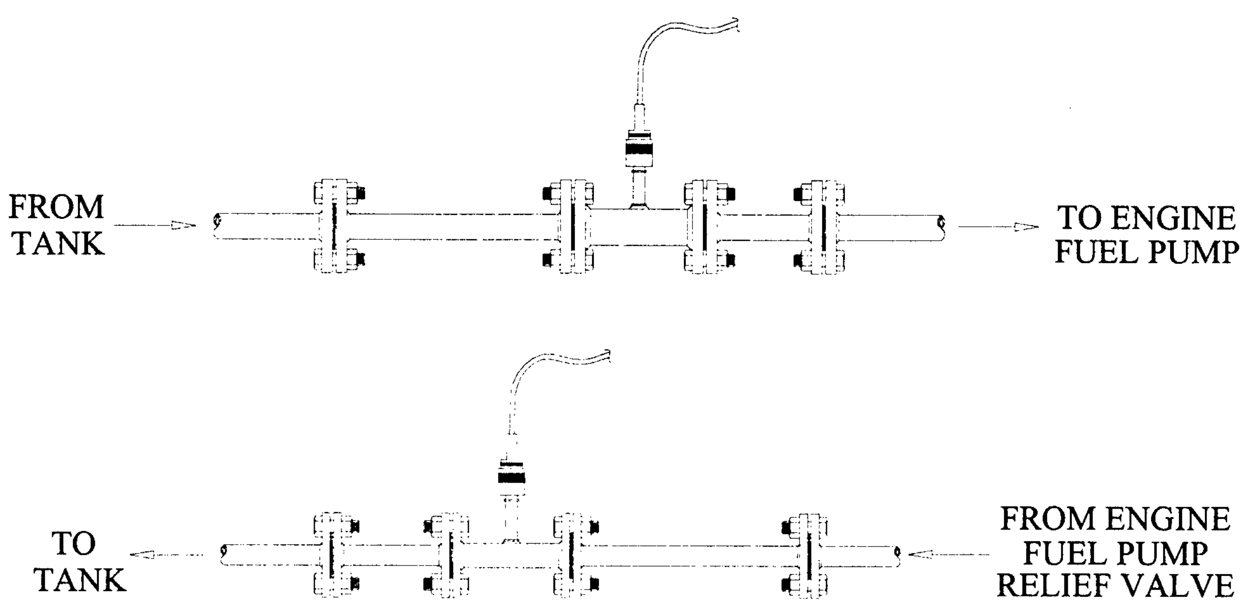

Figure 5-1. Fuel oil meter arrangement.

The WHEC 378' Class cutters now have fuel oil meters installed for the two gas turbine engines. However, the crew of the USCG SHERMAN reported that these meters are seldom used and are normally bypassed. Re-locating the display units for these meters to a central location and close to the display units for the new diesel engine fuel meters, if fitted, may increase their use. While fuel meters are being investigated and/or purchased for the diesel engines, new fuel meters for the cutters' gas turbine engines should be considered, as well, if questions as to the reliability or accuracy of the existing meters is the cause for their non-use. Hoffer also offers a 1½" version of the SY-100 fuel oil meter that is the same unit installed in most U.S. Navy gas turbine powered vessels.

Because accurate fuel flow measurement capability and the ability to frequently observe and quantify changes in fuel consumption are cornerstones of any successful shipboard energy efficiency effort, consideration should be given to establishing a program to evaluate, purchase and install FOMs on a fleetwide, prioritized basis. Initially and at a minimum, a test and evaluation effort should be implemented whereby at least one cutter in each of the classes audited as part of this project is fitted with a fuel oil metering system of the type described above.

5.1.2 Other Energy Efficiency Monitoring Instrumentation

There are two devices that have in the past proven to be extremely useful tools in the conduct of various shipboard energy efficiency activities, the torsion meter and the electronic diesel engine analyzer. The torsion meter can provide accurate measurement and readings of shaft horsepower and rpm produced by the propulsion plant. Shaft horsepower, when coupled with fuel flow data, can be used to evaluate the performance of individual diesel engines with regard to current fuel utilization efficiency. Simplistically, this information indicates how effectively the engine is converting the energy in the fuel it burns into mechanical output power. This information, along with the power reading and its corresponding torque and rpm values can also assist in trouble-shooting and resolving engine and component mechanical and performance problems. Additionally, measured horsepower values, when plotted versus corresponding cutter speeds over time, can also provide precise insight into underwater hull and propeller fouling and roughness conditions and assist in the scheduling and conduct of corrective in-water or drydock maintenance actions (e.g., inspection, cleaning, painting, etc.). Typically, torsion meters are permanently installed, but most manufacturers also offer portable versions that are suitable for shipboard testing requirements.

With advances in electronic component miniaturization, hand held portable electronic diesel engine analyzers have become a very effective tool for evaluating diesel engine performance and condition. The analyzer essentially "looks inside" the engine while it is running to obtain a picture of each cylinder's current condition and performance. Data obtained from a typical cylinder trace can be used to develop pressure versus volume curves, which are used to compute indicated horsepower (IHP). These curves, in conjunction with cylinder firing pressures and

exhaust temperatures, help to identify degraded components and conditions. Examples of frequently diagnosed problems include burned valves, fouled injector tips and mis-timed valve openings and fuel injection, all of which contribute to decreased engine efficiency and increased fuel consumption. These devices also include a customized, PC compatible data analysis software package that processes the raw data downloaded from the portable data collector and provides the operator with a cylinder by cylinder evaluation of condition and performance.

The installed cost of a torsion meter can range from $12,000 to $40,000 per shaft, depending on type, make, and model; shaft size; and plant type and configuration. The acquisition cost of a portable electronic diesel engine analyzer ranges from $10,000 to $20,000, depending on the number of features incorporated, training and commissioning services provided, etc., exclusive of any computer and peripheral equipment costs. Appendix E contains descriptive literature on a representative torque meter and engine analyzer.

5.2 Machinery Component Modifications and Upgrades

As a result of observations made and investigations carried out during the underway energy audits on USCGCs RESOLUTE, JUNIPER, TAHOMA and SHERMAN, certain operating procedures and conditions were identified that contribute to excess fuel consumption and increased machinery maintenance burdens. These items are described below, along with recommended corrective operating procedure changes and corresponding equipment modifications and upgrades. The following operating procedure changes and equipment modifications and retrofits are also applicable to all cutters in the WMEC 210', WLB 225', WMEC 270' and/or WHEC 378' classes and should also be considered for any similarly configured cutter classes in the USCG Fleet.

5.2.1 Standby Engine Lube Oil Heating System (WMEC 270)

Current operating procedures observed on TAHOMA while in single shaft mode require that the off-line engine be maintained in a relatively high level of readiness and responsiveness, with lube oil temperatures kept at or above 145°F. Maintaining lubricating oil within the engine's designed temperature and viscosity range assists in minimizing the wear and potential breakdown of internal components during the cold rapid engine loading that occurs during start-up. Since the main engines are fitted with attached lube oil pumps, the only method for pre-lubricating the engine prior to starting is with a hand-driven pump. Additionally, because no lube oil system or sump heaters are installed, the current method for heating the lube oil in the off-line engine and is to start and keep it running at idle until its lube oil temperature is within limits. For example, because the TAHOMA frequently operates in relatively cool seawater (Districts one and five), the standby engine is generally run for approximately 15 minutes every hour to maintain adequate lube oil temperature. If another method of heating and circulating the lube oil is made available in the cutter, such as a sump heater or a lube oil recirculation loop consisting of a pump and an electric or jacket water heater (from the on line engine), reduced engine starts and operating hours, decreased engine maintenance and a fuel consumption reduction of approximately 900 gallons per year per cutter can be achieved. This modification is applicable to any class fitted with multiple main diesel engines (e.g., WMEC 210' and 270', WLB 225', WHEC 378) where periodic starting and idling is now being used to keep a standby engine in an immediate, ready-to-operate condition while underway.

5.2.2 Auxiliary Steam and Potable Water Production Systems (WMEC 210' and WHEC 378')

The single largest consumer of auxiliary steam while USCGC RESOLUTE is underway is the distilling unit. The existing MECO 3SF3000 distiller utilizes a combination of SSDG engine jacket water and auxiliary boiler-supplied steam for the heat necessary to generate fresh potable water. The observed distiller output was 2,419 gallons per day, or 80 percent of the rated output of 3,000 gallons per day. Replacement of the existing unit with a new reverse osmosis (RO) water maker would reduce energy consumption for this purpose to about 7 kW_E per hour. Total cost for a retrofit installation of this type is estimated at $20,000. This retrofit would eliminate

the use of steam for fresh water generation and could result in an at-sea fuel savings of 35 gallons per day, or approximately $5,000 per year, yielding a simple payback period for RO unit installation of four (4) years. Additional savings opportunities for the auxiliary steam system could be realized by de-rating the boiler firing rate to increase boiler firing cycle time and by optimizing boiler excess air levels. (The energy management audit report for the RESOLUTE contains more details on the RO plant and associated costs).

Immediate fuel savings opportunities on the USCGC SHERMAN's auxiliary steam system can also be realized by routinely operating one auxiliary boiler at any given time, rather than the routine policy of operating both boilers in parallel. Very rarely will WHEC 378 Class cutters need to operate both boilers to satisfy steam demands. However, some cutters are not adequately equipped with chemical treatments, test equipment, or procedures to ensure reliable corrosion free condition for the standby boiler. A boiler water treatment program will eliminate corrosion attack in a wet boiler during prolonged periods of down time and ensure reliable operation at a later date. Alternatively, or in conjunction with chemical treatment, a warming system could also be fitted whereby a steam coil in the standby boiler (supplied by the on-line unit) would keep 0.25 psig of pressure on the idle boiler, helping to reduce corrosion and while keeping it in a warmed up, ready for immediate service condition. For a WHEC 378 Class cutter, the initial boiler water test and chemical dosing equipment installation (one time cost) is estimated at $5,000, with chemical treatment costs estimated at $3,000, annually, for 180 days of boiler operation. Based on typical cutter steam requirements, operation of a single auxiliary boiler instead of two boilers will save approximately 70 gallons of fuel per day, or approximately $9,000 per year per cutter.

The single largest consumer of auxiliary steam while USCGC SHERMAN is underway is the distilling unit. The existing MAXIM Model TU106HR six stage distiller uses auxiliary steam as the source of the heat necessary to generate fresh water. The observed output of the unit was 10,560 gallons per day, or 106 percent of its rated capacity of 10,000 gallons per day. While utilizing the same electrical power demand as the installed unit (30 kW) and no auxiliary steam, cutter potable water demands could be met with a 13,210 gallon RO unit. The total cost for a retrofit installation of this type is estimated at $60,000. This retrofit would eliminate the use of

steam for potable water generation and would result in an at-sea fuel savings of 175 gallons per day, or approximately $23,000 per year, yielding a simple payback period for RO unit installation of three (3) years. (The energy audit report for SHERMAN contains more details on the proposed boiler water treatment system and RO water plant.)

Table 5-1 below summarizes the potential fuel savings achievable from implementing the modifications and upgrades described above to the applicable cutter classes.

Table 5-1. Retrofit/upgrade fuel savings projections, per cutter.

Class	Fuel Savings, Gallons Per Year / $ Per Year		
	Standby Engine Warming System	RO Distilling Plant	Single Boiler Operation
WMEC 210'	1,000/$900	5,560/$5,000	N/A
WLB 225'	1,000/$900	N/A*	N/A
WMEC 270'	1,000/$900	N/A	N/A
WHEC 378'	1,000/$900	25,560/$23,000	10,000/$9,000

* N/A = Not Applicable

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6.0 ANNUAL CUTTER CLASS MISSION PROFILES AND FUEL CONSUMPTION TOTALS

The purpose of this Section is to present annual mission profiles and average per cutter fuel consumption rates for the WMEC 210', WLB 225', WMEC 270' and WHEC 378' Classes and the Coast Guard Districts in which they operate. Paragraph 6.1 provides a brief description of the development of these mission profiles. Paragraph 6.2 presents a summary of average per-cutter in port, underway and total annual fuel consumption for the subject classes. The information presented and described in the following paragraphs of this section was also utilized to develop the annual per-cutter and per-class fuel consumption savings projections shown and discussed in Sections 3.1, 3.2 and 4.3. It is noted that the operational history of the WLB class is too short to provide statistically valid projections. The available data are presented, but should be used with caution.

6.1 Mission Profiles

6.1.1 Class vs. Mission Profiles

Using operating hours obtained from the most recent available Class Abstracts of Operation, AOPS, representative mission profiles were developed for the WMEC 210', WMEC 270', and WHEC 378' (Fiscal Years 1993, 94, 95, 96 and 97) and WLB 225' (Fiscal Years 1996, 1997, 1998 and the first three quarters of 1999). For the purposes of this analysis, all of the varying mission types reported in the class AOPS reviewed were assigned to one of the seven general mission categories listed and briefly described below.

- DRUG INTERDICTION: Air and surface enforcement of laws and treaties (ELT).
- FISHERIES PATROL: Domestic and foreign ELT.
- IMMIGRATION INTERDICTION: Migrant ELT.
- MILITARY /COOPERATIVE EXERCISES: Federal, state and local cooperative exercises, international affairs, military exercises, peace and wartime military operations, and military port security.
- SEARCH AND RESCUE (SAR): Search and rescue operations.

- TRAINING OPERATIONS: Cadet and officer training, military operations and refresher training, and U.S. Coast Guard reserve operations.
- OTHER: Various mission such as polar operations, domestic ice-breaking, port safety and security, public affairs, recreational boat safety and marine inspections, aids to navigation and radar navigation training, bridge administration, marine environmental protection (MARPOL, operations and enforcement), marine science activities, marine sanctuary patrols, other ELT and miscellaneous operations.

Table 6-1 presents, in histogram format, a breakdown of mission profiles for the WMEC 210', WLB 225', WMEC 270' and WHEC 378' Classes as a percentage of total annual average per cutter underway operating hours derived from the Class AOPS data discussed previously.

Table 6-1. Class vs. mission, hours per year and percent of total.

	WMEC 210'		WLB 225'		WMEC 270'		WHEC 378'	
Drug	759	(28%)	0	(0%)	1,104	(33%)	1,449	(46%)
Fisheries	600	(22%)	138	(10%)	573	(17%)	487	(15%)
Immigration	865	(32%)	66	(5%)	953	(29%)	419	(13%)
Military	64	(2%)	60	(4%)	143	(4%)	298	(9%)
Search and Rescue	77	(3%)	11	(1%)	111	(3%)	261	(8%)
Training	179	(7%)	271	(20%)	296	(9%)	164	(5%)
Other	140	(5%)	834	(60%)	138	(4%)	86	(3%)
Total	2,684	(100%)	1,379	(100%)	3,317	(100%)	3,163	(100%)

In addition to underway operating hours and mission data, the class AOPS data reviewed as part of this effort also included a record of annual in-port (not underway) hours for each cutter with its ship's service electrical power generation and distribution system, and when applicable, its auxiliary boiler in operation. Average annual hours of in-port operation are summarized below for each class.

Class	**In-Port Hours/Year**
WMEC 210'	314
WLB 225'	625
WMEC 270'	327
WHEC 378'	562

6.1.2 District vs. Mission Profiles

The AOPS on which the previously described class mission profiles are based also contained detailed information with regard to the district(s) in which each mission was completed. This data was extracted for the following 10 districts.

CGD01 - Boston, Massachusetts
CGD05 - Portsmouth, Virginia
CGD07 - Miami, Florida
CGD08 - New Orleans, Louisiana
CGD09 - Cleveland, Ohio
CGD11 - Alameda, California
CGD13 - Seattle, Washington
CGD14 - Honolulu, Hawaii
CGD17 - Juneau, Alaska
GL - Global

From the available information, representative overviews of the time spent by each class in each district and the relative distribution of missions carried out in each district were also developed. Table 6-2 presents the relative distribution of underway operating time spent per cutter for each class in each district.

Table 6-2. Distribution of annual operating profile by district and class, hours/year (%).

	WHEC 378'		WLB 225'		WMEC 210'		WMEC 270'	
CGD01	22	(1%)	760	(55%)	264	(8%)	607	(19%)
CGD05	14	(1%)	104	(8%)	128	(4%)	280	(9%)
CGD07	322	(12%)	28	(2%)	1,945	(59%)	2,068	(65%)
CGD08	0	(0%)	0	(0%)	198	(6%)	68	(2%)
CGD09	0	(0%)	75	(5%)	0	(0%)	3	(0%)
CGD11	484	(18%)	20	(1%)	225	(7%)	2	(0%)
CGD13	121	(5%)	0	(0%)	354	(11%)	0	(0%)
CGD14	353	(13%)	314	(23%)	0	(0%)	0	(0%)
CGD17	1,006	(37%)	0	(0%)	65	(2%)	7	(0%)
GL	362	(13%)	78	(6%)	138	(4%)	128	(4%)
Total	2,684	(100%)	1,379	(100%)	3,317	(100%)	3,163	(100%)

Appendix F contains a more detailed discussion and presentation of cutter class and district mission profiles, including AOPS source data.

6.2 Annual Fuel Consumption

The following class average annual fuel consumption totals per cutter, were determined from the average of two and a half years of data gathered by LCDR M. Walz, USCG R&D Center. Appendix G contains the source data for the WMEC 210', WMEC 270' and WHEC 378' classes. These totals compare favorably (within 6%) of an independent and separate operations energy model developed by the Logistics Management Institute for Headquarters in August 1999 titled "Forecasting Fuel Consumption USCG Aircraft and Cutters," document CG901T1. Since the operational history of the WLB is too short to make meaningful projections, no data on annual fuel consumption are presented for that class.

Table 6-3. Annual fuel consumption per cutter.

Class	Gallons/Year Per Cutter
WMEC 210	253,413
WMEC 270	372,315
WHEC 378	867,827

The average total annual per cutter consumption rate shown above for each class is comprised of fuel burned in-port and underway. Using various operating hour data extracted from the previously referenced AOPS data, information obtained from cutter crew interviews, SSDG and auxiliary boiler design performance specifications and measured underway consumption rates, these per cutter totals were apportioned into estimates of annual in-port and underway fuel consumption sub-totals in gallons per year.

The Headquarters operations energy budget model effort calculated Coast Guard wide composite fuel consumption rates by asset class by hour as follows with very high confidence levels.

SHIP CLASS FUEL BURN RATE

	(Gallons per Hour)
210	81.9
270	117.7
378	265.1

More specific data can be found in the August 1999 study available from the Energy Resource and Program Manager at Headquarters (G-CFP) at (202) 267-0991.

Table 6-4 presents an estimate of the fuel consumed in port annually, per cutter, for the WMEC 210', WMEC 270' and WHEC 378' Classes. Hourly in-port electric loads have been assumed as 50% of the rated output of one SSDG. Where applicable, the observed hourly underway fuel consumption rate for one auxiliary boiler, as recorded during the applicable underway energy management audit, has been adjusted and added to the design predicted SSDG hourly fuel consumption rate to develop a total combined hourly in-port fuel utilization rate.

Table 6-4. Estimated annual per cutter in-port fuel consumption.

Class	Hours/Year In-Port	Fuel Rate [gal/hr]	Fuel Consumed Gallons/Year
WMEC 210'	314	11.3*	3,548
WMEC 270'	327	25	8,175
WHEC 378'	562	22.1*	12,420

* Combined Rate for One SSDG and One Auxiliary Boiler (No Distiller Operation)

Tables presented in Appendix H present estimates of average per cutter total annual underway fuel consumption vs. mission for the WMEC 210', WLB 225', WMEC 270' and WHEC 378'. As shown in these tables, the total fuel consumption for each mission was estimated based on the percentage of time spent in each speed regime, the corresponding cutter fuel rates taken from speed curves developed during the energy management audits discussed earlier in Section 2.0 and the average annual per cutter mission hours derived from the AOPS records for each class. The speed regimes and time spent at each speed as a percentage were developed from information obtained from cutter crew interviews and log book and other operating record reviews conducted during the subject energy management audits.

Table 6-5 shows the distribution of per cutter annual underway fuel utilization by District for the WMEC 210', WMEC 270' and WHEC 378' Classes. This table was developed by combining mission operating profiles and annual fuel consumption data presented in Appendix H and the cutter class, district and mission information also presented earlier in Tables 6-1 and 6-2.

Table 6-5. District vs. class fuel utilization, gallons per cutter per year and percent of total.

	WMEC 210'		WMEC 270'		WHEC 378'	
CGD01	16,150	(6%)	63,200	(17%)	9,630	(1%)
CGD05	7,470	(3%)	31,200	(9%)	6,950	(1%)
CGD07	161,000	(65%)	247,000	(68%)	166,000	(19%)
CGD08	13,600	(5%)	7,550	(2%)	0	(0%)
CGD09	0	(0%)	362	(0%)	0	(0%)
CGD11	16,700	(7%)	147	(0%)	215,000	(25%)
CGD13	21,100	(8%)	0	(0%)	30,200	(4%)
CGD14	0	(0%)	0	(0%)	82,800	(10%)
CGD17	3,590	(1%)	673	(0%)	154,000	(18%)
GL	9,980	(4%)	13,700	(4%)	190,000	(22%)
Sum	249,900	(100%)	364,000	(100%)	855,000	(100%)

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7.0 CONCLUSIONS

Based on the data and information collected during the underway energy management audits conducted on the USCGCs RESOLUTE, JUNIPER, TAHOMA and SHERMAN and presented and discussed in the previous sections of this report, the following significant conclusions can be drawn.

- Substantial cumulative fuel savings of 19.4, 20.8, 11.2 and 23.4 percent of current annual fuel consumption rates can be achieved for the WMEC 210', WLB 225', WMEC 270' and WHEC 378' cutter classes, respectively. Annual savings for the WMEC and WHEC classes are shown in Table 7-1, but no projections are made for WLB class due to its limited operational history to date.

Table 7-1. Projected annual savings, per class*.

Energy efficiency Strategy	Fuel Savings, **Gallons Per Year**/$ Per Year		
	WMEC 210' (15 Cutters)	WMEC 270' (13 Cutters)	WHEC 378' (12 Cutters)
1. Economic Alignments	**120,000**/$108,000	**55,900**/$50,300	**1,350,000**/$1,210,000
2. Pitch Optimization	**112,500**/$101, 000	**141,700**/$127,500	**307,200**/$276,500
3. One Knot Speed Reduction***	**408,000**/$367,200	**332,000**/$298,800	**338,000**/$304,200
4. Upgrades/ Retrofits	**98,400**/$88,600	**13,000**/$11,700	**439,000**/$395,100
Total Savings Per Class:	**738,900**/$665,000	**542,600**/$488,300	**2,434,200**/$190,800
% of Annual Fuel Consumption:	19.4%	11.2%	23.4%

* Economic alignments, pitch optimization, and speed reduction savings are based on application during 50% of a cutter's operating hours. Upgrades/retrofits would apply 100% of the time.

** All savings shown above are based on an assumed fuel price of $.90 per gallon.

*** Earlier tables show various speed reductions. Savings for the more realistic one knot reduction are shown above are calculated in Appendix C.

These savings can be achieved by implementing the following energy efficiency strategies, which can be incorporated with minimal, if any, additional capital investment.

1. Economic machinery alignments.

2. One knot speed reduction.
3. Propeller pitch optimization.
4. Class specific machinery component retrofits and enhanced operating procedures.

- Propeller pitch schedule optimization offers the greatest potential for achieving continuous cutter fuel consumption reductions without modifying current cutter operating procedures or speed profile.
- Installation of a fuel oil metering system should be accomplished on an initial trial basis in at least one cutter in each of the 210', WLB 225', WMEC 270' and WHEC 378' Classes. Access to accurate, reputable fuel oil consumption measurement systems by cutter crews is an absolute necessity for fuel curve development, propeller pitch schedule optimization, and machinery systems and underwater hull performance and condition assessment. Onboard fuel meters can assist in monitoring and sustaining the results of other energy efficiency strategies implemented by the ship's force.
- Serious consideration should also be given to fitting a lead ship in each class with a torsion meter and a portable electronic diesel engine analyzer to provide additional detailed analysis capability for evaluating the effects of main and auxiliary engine and underwater hull condition and performance on total cutter fuel consumption rates.
- A centralized fuel utilization management system that is capable of allocating and monitoring cutter underway and in-port fuel consumption on a daily, quarterly and annual basis should be developed and applied across the entire USCG fleet. The system should include an incentive award component to help sustain energy efficiency awareness and motivation for personnel at the deck plate level where all fuel savings will be achieved.
- The following additional energy efficiency practices, previously described in detail in Section 3.4, should also be instituted (or continued) at the cutter level across the entire fleet to achieve additional fuel savings.
    - Fuel curve development and use.
    - Hull and propeller condition monitoring and maintenance.
    - Ship's service electric load reduction.
    - Combustion air and fuel oil systems monitoring and maintenance.
    - Main and auxiliary machinery plant condition assessment and maintenance.

APPENDIX A. PROJECTED FUEL SAVINGS FROM ECONOMIC MACHINERY ALIGNMENTS

Table A-1. WMEC 210' Class annual savings from economic alignment.

Mission	Machinery Alignment	Speed Profile Hours at Speeds	Fuel Rate [GPH]	Fuel Consumed Per Mission [Gallons]	Fuel Saved Per Mission Compared to Table H-1 [Gallons]
Drug	Single Engine (pitch optimized)	380 (50%) @ 8 kts.	36.0	79,600	4,100
	Single Engine (pitch optimized)	114 (15%) @ 10 kts.	64.9		
	Two Engines	114 (15%) @ 14 kts.	128		
	Two Engines	152 (20%) @ 17 kts.	289		
Fisheries	Single Engine (pitch optimized)	300 (50%) @ 8 kts.	36.0	35,900	4,100
	Single Engine (pitch optimized)	210 (35%) @ 10 kts.	64.9		
	Two Engines	90 (15%) @ 14 kts.	128		
	Two Engines	0 @ 17 kts.	289		
Immigration	Single Engine (pitch optimized)	433 (50%) @ 8 kts.	36.0	81,000	5,000
	Single Engine (pitch optimized)	173 (20%) @ 10 kts.	64.9		
	Two Engines	130 (15%) @ 14 kts.	128		
	Two Engines	130 (15%) @ 17 kts.	289		
Military	Single Engine (pitch optimized)	38 (60%) @ 8 kts.	36.0	6,300	340
	Single Engine (pitch optimized)	0 @ 10 kts.	64.9		
	Two Engines	16 (25%) @ 14 kts.	128		
	Two Engines	10 (15%) @ 17 kts.	289		
Search and Rescue	Single Engine (pitch optimized)	39 (50%) @ 8 kts.	36.0	12,700	300
	Single Engine (pitch optimized)	0 @ 10 kts.	64.9		
	Two Engines	0 @ 14 kts.	128		
	Two Engines	39 (50%) @ 17 kts.	289		
Training	Single Engine (pitch optimized)	71 (40%) @ 8 kts.	36.0	11,800	1,100
	Single Engine (pitch optimized)	71 (40%) @ 10 kts.	64.9		
	Two Engines	36 (20%) @ 14 kts.	128		
	Two Engines	0 @ 17 kts.	289		
Other	Single Engine (pitch optimized)	70 (50%) @ 8 kts.	36.0	7,060	1,070
	Single Engine (pitch optimized)	70 (50%) @ 10 kts.	64.9		
	Two Engines	0 @ 14 kts.	128		
	Two Engines	0 @ 17 kts.	289		
			Total Underway	234,400	16,000

Table A-2. WLB 225' Class annual savings from economic alignment.

Mission	Machinery Alignment	Speed Profile Hours at Speeds	Fuel Rate [GPH]	Fuel Consumed Per Mission [Gallons]	Fuel Saved Per Mission Compared to Table H-2 [Gallons]
Drug	Single Engine Two Engines Two Engines Two Engines	0 @ 8 kts. 0 @ 10 kts. 0 @ 14 kts. 0 @ 17 kts.	34.1 47.0 112 264	0	0
Fisheries	Single Engine Two Engines Two Engines Two Engines	69 (50%) @ 8 kts. 0 @ 10 kts. 69 (50%) @ 14 kts. 0 @ 17 kts.	34.1 47.0 112 264	10,100	3,400
Immigration	Single Engine Two Engines Two Engines Two Engines	0 @ 8 kts. 33 (50%) @ 10 kts. 20 (30%) @ 14 kts. 13 (20%) @ 17 kts.	34.1 47.0 112 264	7,220	200
Military	Single Engine Two Engines Two Engines Two Engines	0 @ 8 kts. 36 (60%) @ 10 kts. 24 (40%) @ 14 kts. 0 @ 17 kts.	34.1 47.0 112 264	4,380	220
Search and Rescue	Single Engine Two Engines Two Engines Two Engines	6 (50%) @ 8 kts. 0 @ 10 kts. 0 @ 14 kts. 6 (50%) @ 17 kts.	34.1 47.0 112 264	1,790	300
Training	Single Engine Two Engines Two Engines Two Engines	0 @ 8 kts. 162 (60%) @ 10 kts. 108 (40%) @ 14 kts. 0 @ 17 kts.	34.1 47.0 112 264	19,700	1,000
Other	Single Engine Two Engines Two Engines Two Engines	417 (50%) @ 8 kts. 0 @ 10 kts. 417 (50%) @ 14 kts. 0 @ 17 kts.	34.1 47.0 112 264	60,900	20,800
			Total Underway	104,100	25,900

Table A-3. WMEC 270' Class annual savings from economic alignment.

Mission	Machinery Alignment	Speed Profile Hours at Speeds	Fuel Rate [GPH]	Fuel Consumed Per Mission [Gallons]	Fuel Saved Per Mission Compared to Table H-3 [Gallons]
Drug	Single Engine Single Engine Single Engine Two Engines	552 (50%) @ 8 kts. 166 (15%) @ 10 kts. 166 (15%) @ 14 kts. 221 (20%) @ 17 kts.	52.8 69.7 133 243	116,000	2,000
Fisheries	Single Engine Single Engine Single Engine Two Engines	286 (50%) @ 8 kts. 115 (20%) @ 10 kts. 172 (30%) @ 14 kts. 0 @ 17 kts.	52.8 69.7 133 243	46,000	1,700
Immigration	Single Engine Single Engine Single Engine Two Engines	0 @ 8 kts. 476 (50%) @ 10 kts. 286 (30%) @ 14 kts. 191 (20%) @ 17 kts.	52.8 69.7 133 243	118,000	2,000
Military	Single Engine Single Engine Single Engine Two Engines	0 @ 8 kts. 72 (50%) @ 10 kts. 72 (50%) @ 14 kts. 0 @ 17 kts.	52.8 69.7 133 243	14,600	700
Search and Rescue	Single Engine Single Engine Single Engine Two Engines	0 @ 8 kts. 55 (50%) @ 10 kts. 0 @ 14 kts. 55 (50%) @ 17 kts.	52.8 69.7 133 243	17,200	0
Training	Single Engine Single Engine Single Engine Two Engines	0 @ 8 kts. 148 (50%) @ 10 kts. 148 (50%) @ 14 kts. 0 @ 17 kts.	52.8 69.7 133 243	30,000	1,500
Other	Single Engine Single Engine Single Engine Two Engines	69 (50%) @ 8 kts. 0 @ 10 kts. 69 (50%) @ 14 kts. 0 @ 17 kts.	52.8 69.7 133 243	12,800	700
			Total Underway	354,600	8,600

Table A-4. WHEC 378' Class annual savings from economic alignment.

Mission	Machinery Alignment	Speed Profile Hours at Speeds	Fuel Rate [GPH]	Fuel Consumed Per Mission [Gallons]	Fuel Saved Per Mission Compared to Table H-4 [Gallons]
Drug	Single Diesel Engine	869 (60%) @ 8 kts.	126	302,000	77,000
	Single Diesel Engine	362 (25%) @ 10 kts.	151		
	Two Diesel Engines	72 (5%) @ 14 kts.	285		
	Two Diesel Engines	72 (5%) @ 17 kts.	422		
	Single Gas Turbine	36 (2.5%) @ 20 kts.	1100		
	Single Gas Turbine	36 (2.5%) @ 22 kts.	1,320		
Fisheries	Single Diesel Engine	244 (50%) @ 8 kts.	126	90,600	46,400
	Single Diesel Engine	122 (25%) @ 10 kts.	151		
	Two Diesel Engines	73 (15%) @ 14 kts.	285		
	Two Diesel Engines	49 (10%) @ 17 kts.	422		
	Single Gas Turbine	0 @ 20 kts.	1100		
	Single Gas Turbine	0 @ 22 kts.	1,320		
Immigration	Single Diesel Engine	251 (60%) @ 8 kts.	126	72,200	30,800
	Single Diesel Engine	84 (20%) @ 10 kts.	151		
	Two Diesel Engines	52 (12.5%) @ 14 kts.	285		
	Two Diesel Engines	31 (7.5%) @ 17 kts.	422		
	Single Gas Turbine	0 @ 20 kts.	1100		
	Single Gas Turbine	0 @ 22 kts.	1,320		
Military	Single Diesel Engine	178 (60%) @ 8 kts.	126	52,500	23,100
	Single Diesel Engine	59 (20%) @ 10 kts.	151		
	Two Diesel Engines	30 (10%) @ 14 kts.	285		
	Two Diesel Engines	30 (10%) @ 17 kts.	422		
	Single Gas Turbine	0 @ 20 kts.	1100		
	Single Gas Turbine	0 @ 22 kts.	1,320		
Search and Rescue	Single Diesel Engine	143 (55%) @ 8 kts.	126	69,900	27,700
	Single Diesel Engine	33 (12.5%) @ 10 kts.	151		
	Two Diesel Engines	39 (15%) @ 14 kts.	285		
	Two Diesel Engines	26 (10%) @ 17 kts.	422		
	Single Gas Turbine	7 (2.5%) @ 20 kts.	1100		
	Single Gas Turbine	13 (5%) @ 22 kts.	1,320		
Training	Single Diesel Engine	66 (40%) @ 8 kts.	126	27,700	12,400
	Single Diesel Engine	66 (40%) @ 10 kts.	151		
	Two Diesel Engines	33 (20%) @ 14 kts.	285		
	Two Diesel Engines	0 @ 17 kts.	422		
	Single Gas Turbine	0 @ 20 kts.	1100		
	Single Gas Turbine	0 @ 22 kts.	1,320		
Other	Single Diesel Engine	43 (50%) @ 8 kts.	126	14,600	7,300
	Single Diesel Engine	21 (25%) @ 10 kts.	151		
	Two Diesel Engines	21 (25%) @ 14 kts.	285		
	Two Diesel Engines	0 @ 17 kts.	422		
	Single Gas Turbine	0 @ 20 kts.	1100		
	Single Gas Turbine	0 @ 22 kts.	1,320		
			Total Underway	629,500	224,700

APPENDIX B. PROPELLER PTICH OPTIMIZATION DISCUSSION AND EXAMPLES

PROPELLER PITCH OPTIMIZATION

The pitch program for a controllable/reversible pitch propeller is generally developed to minimize cavitation and avoid poor combinations of RPM and torque for the engine. There is rarely one pitch schedule that perfectly matches engine fuel efficiency with these considerations throughout the entire speed and power range. Tests performed on two of the audited cutters demonstrated that the single engine automated pitch schedule was not the optimum from a fuel consumption standpoint. Figures B-1 and B-2 show the fuel consumption curves generated from data collected on the WLB 201 and WMEC 620. In both cases anomalous single engine fuel consumption that was greater than their respective twin engine operation at the same speeds were recorded.

Testing by the ship's force going outside the program pitch schedule with various pitches and rpm's to produce the desired speed while monitoring fuel oil flow meters can be accomplished easily without jeopardizing vessel missions. New pitch programs can then be created and entered into the ship's control logic after identification of the most fuel efficient pitch/rpm combination and the resultant overall effects on the machinery plant have been determined. In some cases, the lowest fuel consuming pitch and rpm combination can cause operation in the smoking portion of an engine's power vs. rpm characteristics and/or result in high exhaust temperatures and brake mean effective pressure (bmep).

The analytical approach of optimizing the pitch schedule for fuel efficiency consists of creating an imaginary propeller curve on a power vs. rpm engine fuel map where the propeller program follows the path through the lowest specific fuel consumption for the expected operating range. This was obviously the method used to establish the two shaft pitch program for the USCGC RESOLUTE as shown in Figure B-3.

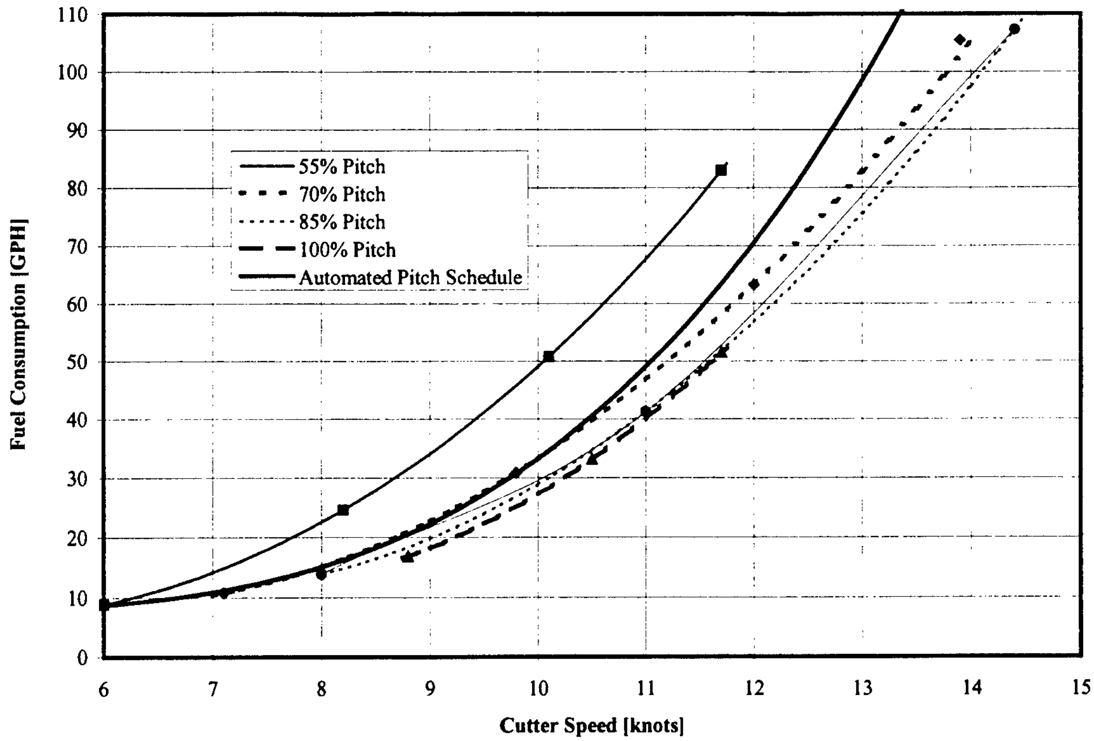

Figure B-1. Single engine pitch optimization USCGC JUNIPER (WLB 201).

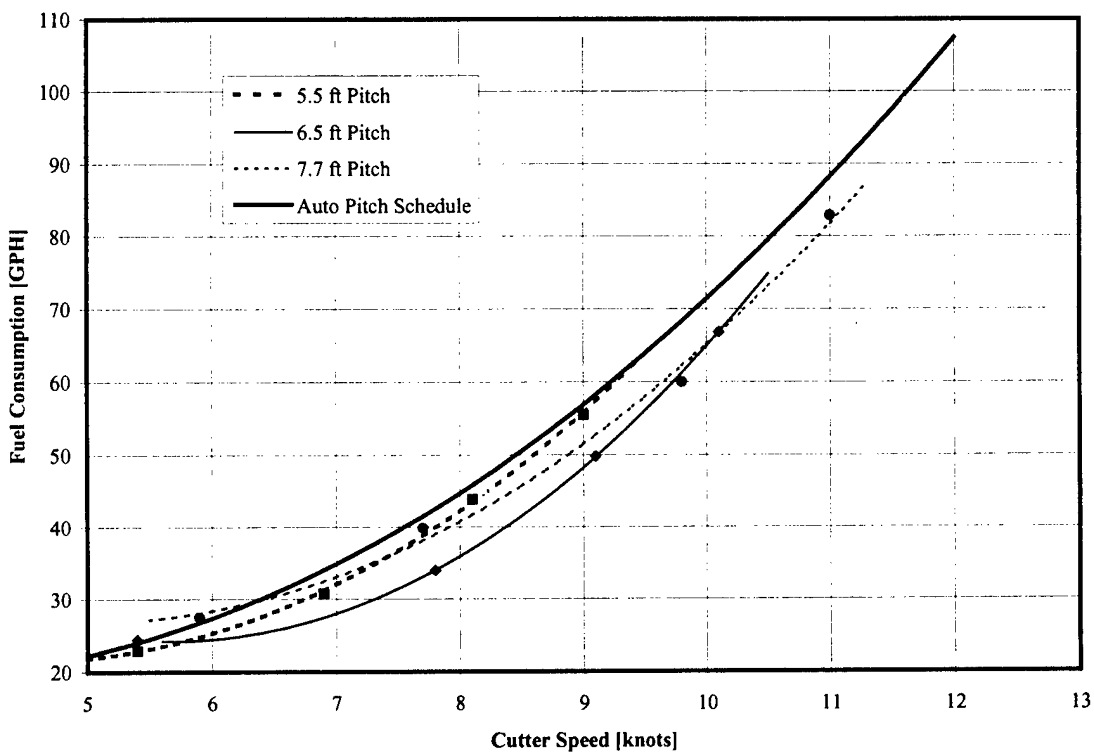

Figure B-2. Single engine pitch optimization USCGC RESOLUTE (WMEC 620).

The optimum program pitch for single shaft operation is difficult to derive from this curve alone, as the additional resistance of the trailing shaft will have a significant impact on the speed-power relationship. As a result, underway testing is required to determine the most fuel efficient propeller pitch schedule.

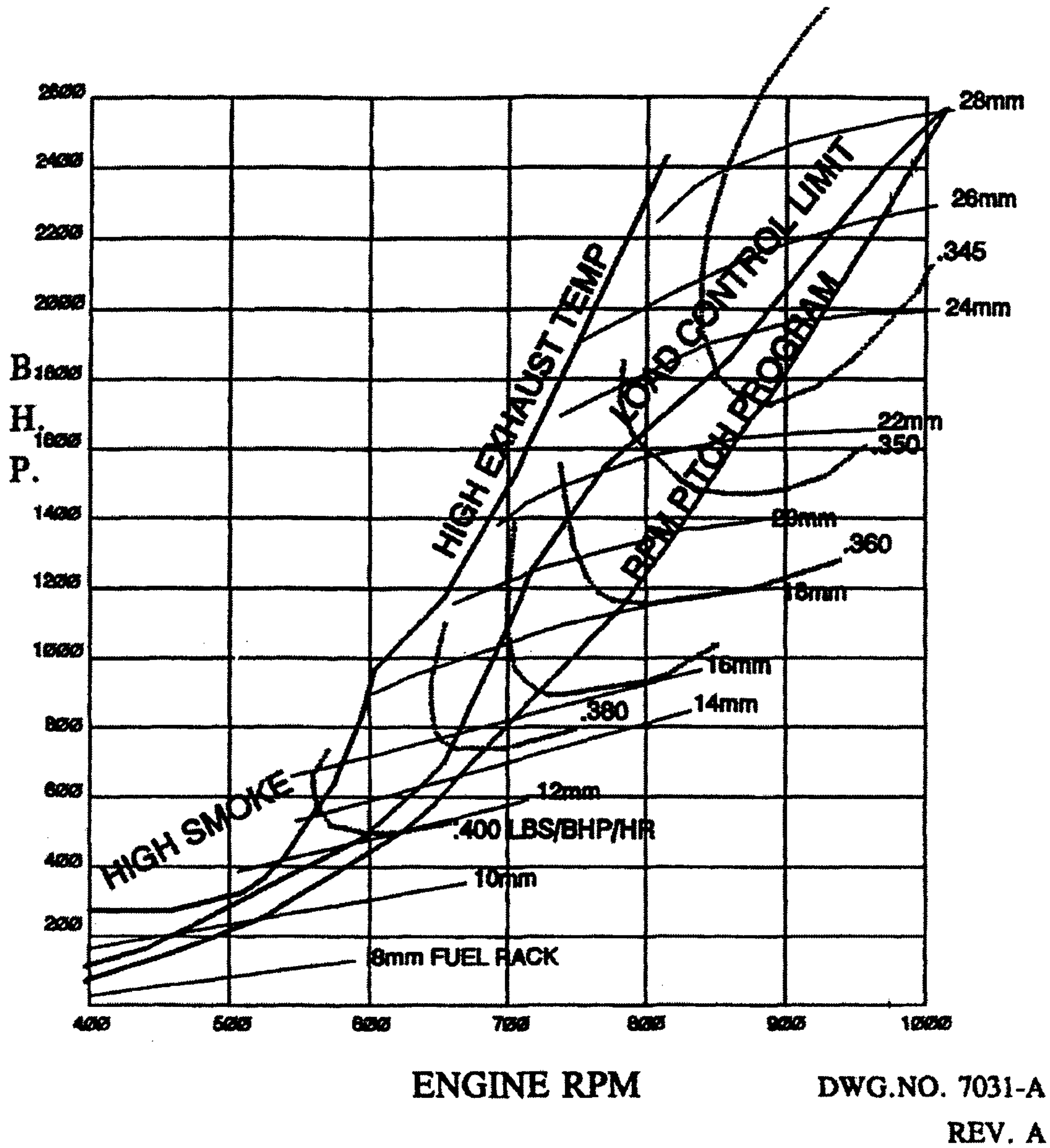

Figure B-3. WMEC 210' Class fuel map and engine load curve, for two shaft operation.

The results of underway testing performed in the RESOLUTE (WMEC 620) as shown in Figure B-2 are typical of what would be expected for single engine/shaft operation. However, further

testing is needed before the final, most efficient pitch schedule can be developed for the single engine/trail shaft mode.

Figure B-4 is a fuel map provided by Caterpillar for its Model 3608 engine, the main propulsion engines installed in the WLB 225' Class cutters. To illustrate the approximate path that a fuel

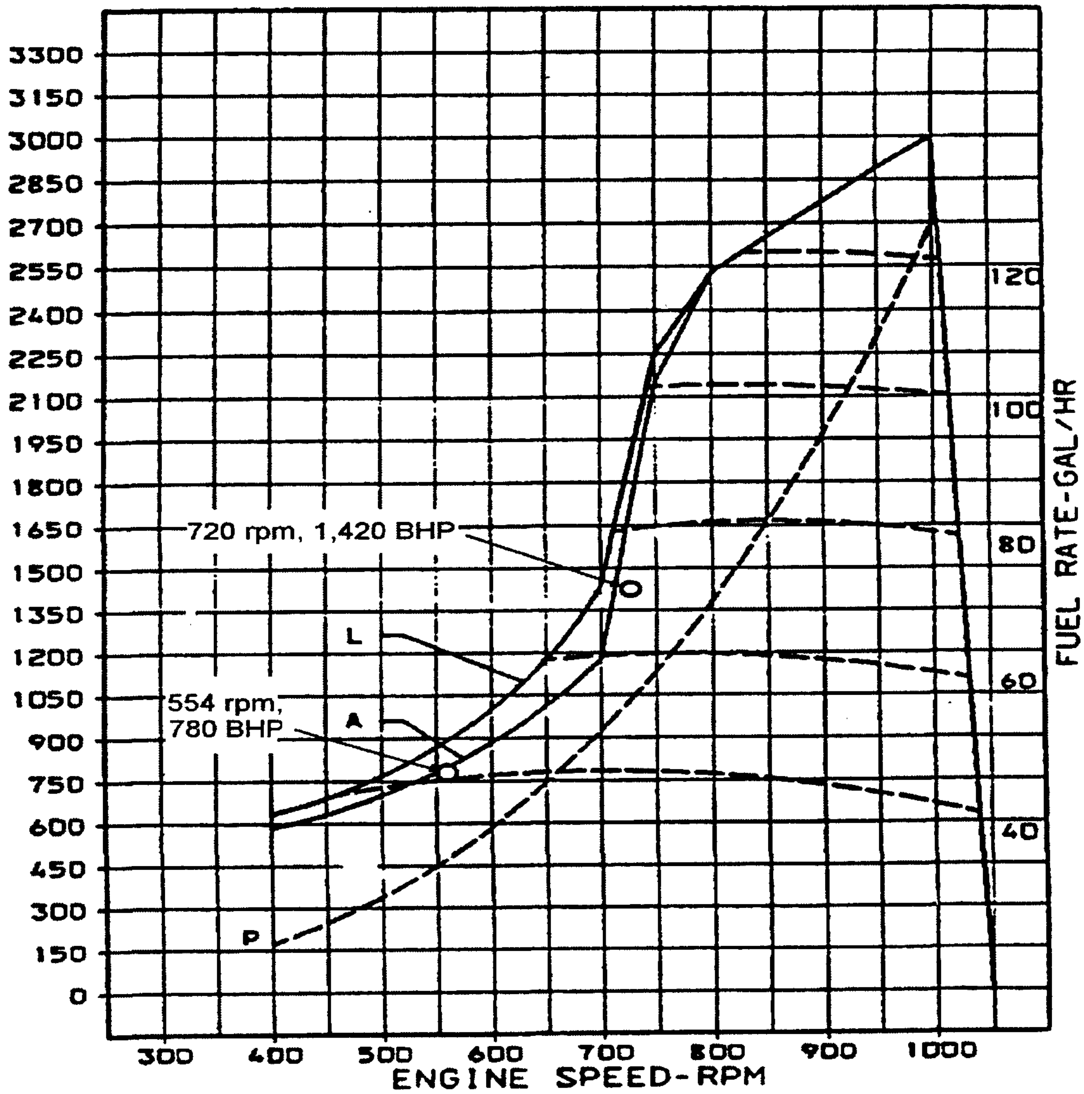

Figure B-4. WLB 225' Caterpillar 3608 engine super-imposed pitch curve.

Ideally, to create this curve shaft power as measured by a torsion meter is required to develop multiple curves for various propeller pitches on the power versus rpm graph. Curves of ship's speed are also needed to account for the variation in propeller efficiency at different combinations of pitch and rpm. Since these curves are not readily available, propeller characteristic curves must by the manufacturer, Bird-Johnson Co., of Walpole, MA, be used. Figure B-5 shows the open water propeller curves.

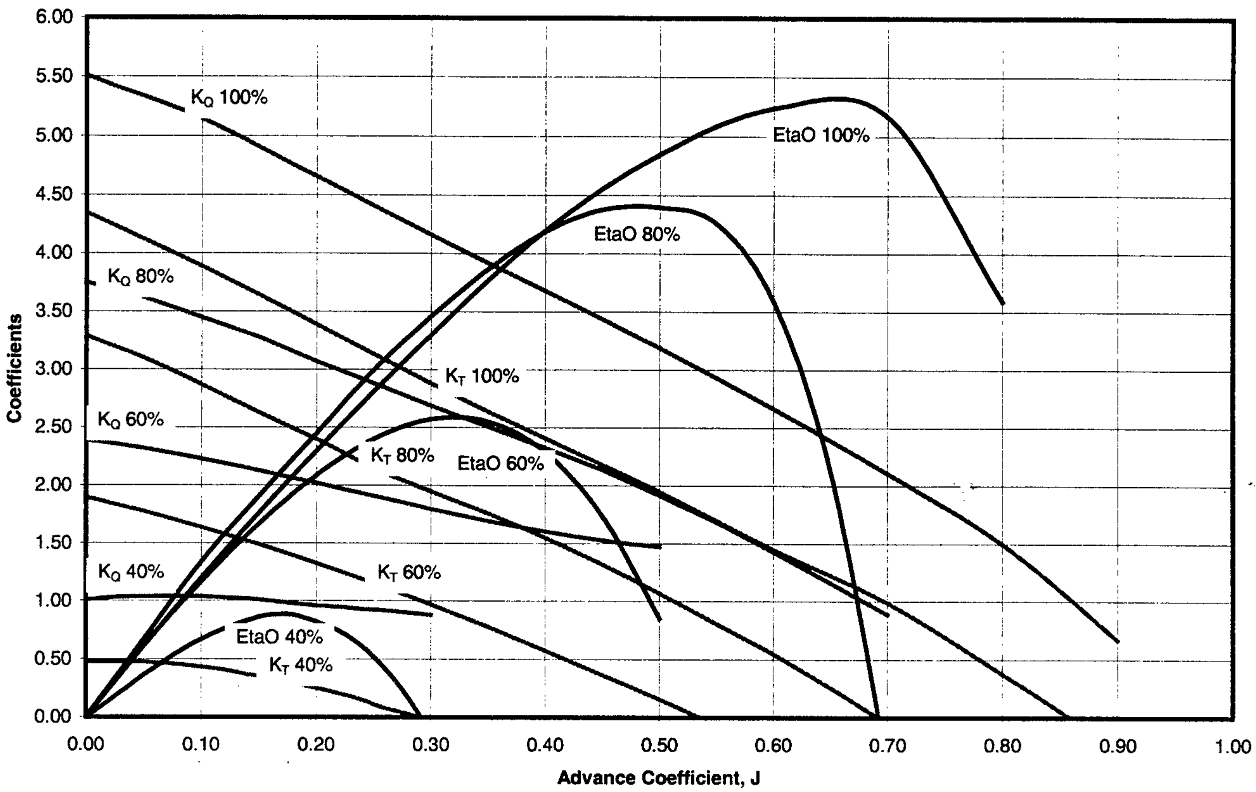

Figure B-5. WLB 225' propeller characteristics (60% pitch interpolated) $10xK_T$, $100xK_Q$, 10xEtaO.

One limiting factor in the effectiveness of using these curves is the lack of consideration of propeller-ship interaction, as these curves were developed from open water test results, and if actual calculations are to be made, the relative rotative efficiency of the propeller must be included. The following equations are used with these curves to determine thrust, torque, and shaft horsepower.

$$J = \frac{V \times (1 - w)}{(n \times D)} \qquad (1)$$

$$Thrust = K_T \times \rho \times n^2 \times D^4 \qquad (2)$$

$$Torque = K_Q \times \rho \times n^2 \times D^5 \qquad (3)$$

$$SHP = \frac{2 \times \pi \times n \times Torque}{550} \qquad (4)$$

Where:

J = Advance Coefficient	n = Shaft RPS [rev/sec]
K_T = Thrust Coefficient	ρ = Density of Water [1.9905 slugs/ft^3]
K_Q = Torque Coefficient	V = Ship Speed [ft/s]
w = Wake Fraction [assume 30%]	D = Propeller Diameter [ft]

An example of this calculation can be made for a speed of 12 knots for the USCGC JUNIPER (WLB 201) where the **as-found single engine program pitch was 63 percent** and shaft speed was 201 rpm (720 engine rpm). The propeller diameter is 10 feet. The resulting advance coefficient is 0.43. Interpolating on Figure 5.5 yields a K_T of 0.0613, a K_Q of 0.0166, and a propeller open water efficiency of 25 percent, which can be used to calculate a thrust of 13,700 lbs, a propeller shaft torque of 37,000 ft-lbs and an engine power of 1,420 BHP (1,060 kW). The resulting fuel map placement (Figure B-4) gives a specific fuel consumption rate of 0.340 lb/hp-hr (207 g/kW-hr) or 69 GPH. This compares favorably with the measured fuel consumption of 72.9 GPH recorded during the audit.

Alternatively, at the same speed a lower rpm and higher pitch can be selected while keeping the thrust constant. With a thrust of 13,700 lbs and a pitch of 85 percent, the matching advance coefficient is 0.553, and the shaft speed is 155 rpm (554 engine rpm). This combination gives a propeller efficiency of 46 percent, a K_T of 0.103, and a K_Q of 0.0198. The corresponding torque is 26,300 ft-lbs and the engine power is 780 BHP (582 kW). The resulting engine specific fuel consumption rate is 0.377 lb/bhp-hr (229 g/kW-hr) which is greater than that for the lower pitch setting. However, since propeller efficiency is greatly increased and engine power is greatly reduced, the required fuel flow is now only 42 GPH. By way of comparison, test data shown on Figure B-1 indicates the 85 percent pitch, 12 knot observed fuel rate is 57 GPH.

Thus, increasing the pitch from the current schedule allows a 45 percent reduction in horsepower, and a fuel reduction between 22 percent and 39 percent.

Both the calculated fuel savings shown above and the data obtained from the limited pitch optimization testing conducted during the subject energy audits indicate that substantial reductions in single engine/shaft mode fuel consumption are achievable via optimization of automatic single engine pitch programs for the WLB 225' and WMEC 210' and 270' and WHEC 378' Classes. Based on these results, consideration should also be given to evaluating and optimizing these automatic single engine operating mode pitch control schedules in all other applicable cutter classes.

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APPENDIX C. PROJECTED FUEL SAVINGS FROM A ONE KNOT SPEED REDUCTION

Table C-1. WMEC 210' Class annual savings from reduced speed.

Mission	Machinery Alignment	Speed Profile Hours at Speeds	Fuel Rate [GPH]	Fuel Consumed Per Mission [Gallons]	Fuel Saved Per Mission Compared to Table A-1 [Gallons]
Drug	Single Engine (pitch optimized) Single Engine (pitch optimized) Two Engines Two Engines	380 (50%) @ 7 kts. 114 (15%) @ 9 kts. 114 (15%) @ 13 kts. 152 (20%) @ 16 kts.	28.0 48.3 102 219	61,100	18,500
Fisheries	Single Engine (pitch optimized) Single Engine (pitch optimized) Two Engines Two Engines	300 (50%) @ 7 kts. 210 (35%) @ 9 kts. 90 (15%) @ 13 kts. 0 @ 16 kts.	28.0 48.3 102 219	27,700	8,200
Immigration	Single Engine (pitch optimized) Single Engine (pitch optimized) Two Engines Two Engines	433 (50%) @ 7 kts. 173 (20%) @ 9 kts. 130 (15%) @ 13 kts. 130 (15%) @ 16 kts.	28.0 48.3 102 219	62,200	18,800
Military	Single Engine (pitch optimized) Single Engine (pitch optimized) Two Engines Two Engines	38 (60%) @ 7 kts. 0 @ 9 kts. 16 (25%) @ 13 kts. 10 (15%) @ 16 kts.	28.0 48.3 102 219	4,890	1,410
Search and Rescue	Single Engine (pitch optimized) Single Engine (pitch optimized) Two Engines Two Engines	39 (50%) @ 7 kts. 0 @ 9 kts. 0 @ 13 kts. 39 (50%) @ 16 kts.	28.0 48.3 102 219	9,630	3,070
Training	Single Engine (pitch optimized) Single Engine (pitch optimized) Two Engines Two Engines	71 (40%) @ 7 kts. 71 (40%) @ 9 kts. 36 (20%) @ 13 kts. 0 @ 16 kts.	28.0 48.3 102 219	9,090	2,710
Other	Single Engine (pitch optimized) Single Engine (pitch optimized) Two Engines Two Engines	70 (50%) @ 7 kts. 70 (50%) @ 9 kts. 0 @ 13 kts. 0 @ 16 kts.	28.0 48.3 102 219	5,340	1,720
			Total Underway	179,950	54,400

Table C-2. WLB 225' Class annual savings from reduced speed.

Mission	Machinery Alignment	Speed Profile Hours at Speeds	Fuel Rate [GPH]	Fuel Consumed Per Mission [Gallons]	Fuel Saved Per Mission Compared to Table A-2 [Gallons]
Drug	Single Engine Single Engine Two Engines Two Engines	0 @ 7 kts. 0 @ 9 kts. 0 @ 13 kts. 0 @ 16 kts.	28.7 35.8 86.0 199	0	0
Fisheries	Single Engine Single Engine Two Engines Two Engines	69 (50%) @ 7 kts. 0 @ 9 kts. 69 (50%) @ 13 kts. 0 @ 16 kts.	28.7 35.8 86.0 199	7,910	2,190
Immigration	Single Engine Single Engine Two Engines Two Engines	0 @ 7 kts. 33 (50%) @ 9 kts. 20 (30%) @ 13 kts. 13 (20%) @ 16 kts.	28.7 35.8 86.0 199	5,490	1,730
Military	Single Engine Single Engine Two Engines Two Engines	0 @ 7 kts. 36 (60%) @ 9 kts. 24 (40%) @ 13 kts. 0 @ 16 kts.	28.7 35.8 86.0 199	3,350	1,030
Search and Rescue	Single Engine Single Engine Two Engines Two Engines	6 (50%) @ 7 kts. 0 @ 9 kts. 0 @ 13 kts. 6 (50%) @ 16 kts.	28.7 35.8 86.0 199	1,370	420
Training	Single Engine Single Engine Two Engines Two Engines	0 @ 7 kts. 162 (60%) @ 9 kts. 108 (40%) @ 13 kts. 0 @ 16 kts.	28.7 35.8 86.0 199	15,100	4,600
Other	Single Engine Single Engine Two Engines Two Engines	417 (50%) @ 7 kts. 0 @ 9 kts. 417 (50%) @ 13 kts. 0 @ 16 kts.	28.7 35.8 86.0 199	47,800	13,100
			Total Underway	81,020	23,100

Table C-3. WMEC 270' Class annual savings from reduced speed.

Mission	Machinery Alignment	Speed Profile Hours at Speeds	Fuel Rate [GPH]	Fuel Consumed Per Mission [Gallons]	Fuel Saved Per Mission Compared to Table A-3 [Gallons]
Drug	Single Engine Single Engine Single Engine Two Engines	552 (50%) @ 7 kts. 166 (15%) @ 9 kts. 166 (15%) @ 13 kts. 221 (20%) @ 16 kts.	47.1 60.2 113 205	100,000	16,000
Fisheries	Single Engine Single Engine Single Engine Two Engines	286 (50%) @ 7 kts. 115 (20%) @ 9 kts. 172 (30%) @ 13 kts. 0 @ 16 kts.	47.1 60.2 113 205	39,800	6,200
Immigration	Single Engine Single Engine Single Engine Two Engines	0 @ 7 kts. 476 (50%) @ 9 kts. 286 (30%) @ 13 kts. 191 (20%) @ 16 kts.	47.1 60.2 113 205	100,000	18,000
Military	Single Engine Single Engine Single Engine Two Engines	0 @ 7 kts. 72 (50%) @ 9 kts. 72 (50%) @ 13 kts. 0 @ 16 kts.	47.1 60.2 113 205	12,500	2,100
Search and Rescue	Single Engine Single Engine Single Engine Two Engines	0 @ 7 kts. 55 (50%) @ 9 kts. 0 @ 13 kts. 55 (50%) @ 16 kts.	47.1 60.2 113 205	14,600	2,600
Training	Single Engine Single Engine Single Engine Two Engines	0 @ 7 kts. 148 (50%) @ 9 kts. 148 (50%) @ 13 kts. 0 @ 16 kts.	47.1 60.2 113 205	25,600	4,400
Other	Single Engine Single Engine Single Engine Two Engines	69 (50%) @ 7 kts. 0 @ 9 kts. 69 (50%) @ 13 kts. 0 @ 16 kts.	47.1 60.2 113 205	11,000	1,800
			Total Underway	303,500	51,100

Table C-4. WHEC 378' Class annual savings from reduced speed.

Mission	Machinery Alignment	Speed Profile Hours at Speeds	Fuel Rate [GPH]	Fuel Consumed Per Mission [Gallons]	Fuel Saved Per Mission Compared to Table A-4 [Gallons]
Drug	Single Diesel Engine	869 (60%) @ 7 kts.	118	276,000	26,000
	Single Diesel Engine	362 (25%) @ 9 kts.	136		
	Two Diesel Engines	72 (5%) @ 13 kts.	252		
	Two Diesel Engines	72 (5%) @ 16 kts.	371		
	Single Gas Turbine	36 (2.5%) @ 19 kts.	996		
	Single Gas Turbine	36 (2.5%) @ 21 kts.	1,210		
Fisheries	Single Diesel Engine	244 (50%) @ 7 kts.	118	82,000	8,600
	Single Diesel Engine	122 (25%) @ 9 kts.	136		
	Two Diesel Engines	73 (15%) @ 13 kts.	252		
	Two Diesel Engines	49 (10%) @ 16 kts.	371		
	Single Gas Turbine	0 @ 19 kts.	996		
	Single Gas Turbine	0 @ 21 kts.	1,210		
Immigration	Single Diesel Engine	251 (60%) @ 7 kts.	118	65,600	6,600
	Single Diesel Engine	84 (20%) @ 9 kts.	136		
	Two Diesel Engines	52 (12.5%) @ 13 kts.	252		
	Two Diesel Engines	31 (7.5%) @ 16 kts.	371		
	Single Gas Turbine	0 @ 19 kts.	996		
	Single Gas Turbine	0 @ 21 kts.	1,210		
Military	Single Diesel Engine	178 (60%) @ 7 kts.	118	47,700	4,800
	Single Diesel Engine	59 (20%) @ 9 kts.	136		
	Two Diesel Engines	30 (10%) @ 13 kts.	252		
	Two Diesel Engines	30 (10%) @ 16 kts.	371		
	Single Gas Turbine	0 @ 19 kts.	996		
	Single Gas Turbine	0 @ 21 kts.	1,210		
Search and Rescue	Single Diesel Engine	143 (55%) @ 7 kts.	118	63,500	6,400
	Single Diesel Engine	33 (12.5%) @ 9 kts.	136		
	Two Diesel Engines	39 (15%) @ 13 kts.	252		
	Two Diesel Engines	26 (10%) @ 16 kts.	371		
	Single Gas Turbine	7 (2.5%) @ 19 kts.	996		
	Single Gas Turbine	13 (5%) @ 21 kts.	1,210		
Training	Single Diesel Engine	66 (40%) @ 7 kts.	118	25,100	2,600
	Single Diesel Engine	66 (40%) @ 9 kts.	136		
	Two Diesel Engines	33 (20%) @ 13 kts.	252		
	Two Diesel Engines	0 @ 16 kts.	371		
	Single Gas Turbine	0 @ 19 kts.	996		
	Single Gas Turbine	0 @ 21 kts.	1,210		
Other	Single Diesel Engine	43 (50%) @ 7 kts.	118	13,200	1,400
	Single Diesel Engine	21 (25%) @ 9 kts.	136		
	Two Diesel Engines	21 (25%) @ 13 kts.	252		
	Two Diesel Engines	0 @ 16 kts.	371		
	Single Gas Turbine	0 @ 19 kts.	996		
	Single Gas Turbine	0 @ 21 kts.	1,210		
			Total Underway	573,100	56,400

APPENDIX D. FUEL OIL METER TECHNICAL LITERATURE

QUOTATION

HOFFER FLOW CONTROLS, INC.
The Turbine Flowmeter Company™

107 Kitty Hawk Lane • P.O. Box 2145 • Elizabeth City, North Carolina 27906-2145

(252) 331-1997
(800) 628-4584
FAX (252) 331-2886

TO: SEAWORTHY SYSTEMS, INC.
22 MAIN STREET
CENTERBROOK, CT 06409
ATTN: TED DIEHL
TEL: (860)767-9061
FAX: (860)767-1263

QUOTE NO. 39065 PAGE 1

DATE OCTOBER 13, 1999

FIRM FOR 60 DAYS NET 30 DAYS UPON CREDIT APPROVAL

F.O.B. ELIZABETH CITY, NC 27909

REFERENCE FUEL OIL

SHIPPING DATE SEE SHIPPING NOTE AT END OF QUOTATION.

WE ARE PLEASED TO PROVIDE OUR QUOTATION ON THE MATERIAL DETAILED BELOW:

ITEM	QTY.	DESCRIPTION
		#BEST Warranty in the Industry! Hoffer HO Precision Series (Liquid and Gas) and API Series of Turbine Flowmeters carry a 5-Year Warranty.
		REGARDING YOUR APPLICATION FOR METERING FUEL OIL USING A HOFFER TURBINE FLOWMETER.
1	2	#HOFFER 3/4" HO PRECISION TURBINE FLOWMETER / SY100 SERIES

RECOMMENDATION IS BASED ON A MAXIMUM OPERATING PRESSURE OF 150 PSIG AND AN AMBIENT OPERATING TEMPERATURE.

MODEL HO3/4X3/4-2.5-29-T-1M-F1SS-SY100

SERVICE FLUID:	FUEL OIL
LINEAR FLOW RANGE:	2.5 TO 29 GPM
REPEATABLE FLOW RANGE:	1.5 TO 35 GPM
LINEARITY:	+/- 2% OF READING OVER THE LINEAR FLOW RANGE.
REPEATABILITY:	+/-0.5% OF READING OVER THE REPEATABLE FLOW RANGE.
CONSTRUCTION:	316 STAINLESS STEEL WITH 17.4 PH ROTOR.
END FITTING:	3/4" 150 # 316 S.S. RAISED FACE FLANGES PER ANSI.
BEARINGS:	TUNGSTEN CARBIDE SLEEVE TYPE.
MAXIMUM ALLOWABLE PARTICLE SIZE:	.007" (80 MESH)
PICKUP COIL:	MAGNETIC TYPE.
CALIBRATION:	SUPPLIED WITH TEN POINT WATER CALIBRATION TRACEABLE TO NIST.
FLOW RANGE FLOWMETER WILL BE CALIBRATED OVER (UNLESS OTHERWISE SPECIFIED)	2.5 TO 29 GPM

LIST PRICE .... $1782.50 EA
RESELLERS PRICE .... $1515.00 EA

QUOTATION

HOFFER FLOW CONTROLS, INC.
The Turbine Flowmeter Company™
107 Kitty Hawk Lane • P.O. Box 2145 • Elizabeth City, North Carolina 27906-2145

(252) 331-1997
(800) 628-4584
FAX (252) 331-2886

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22 MAIN STREET
CENTERBROOK, CT 06409
ATTN: TED DIEHL
TEL: (860)767-9061
FAX: (860)767-1263

QUOTE NO 39065 PAGE: 2

DATE OCTOBER 13, 1999

FIRM FOR 60 DAYS NET 30 DAYS UPON CREDIT APPROVAL

F.O.B. ELIZABETH CITY, NC 27909

REFERENCE: FUEL OIL

SHIPPING DATE: SEE SHIPPING NOTE AT END OF QUOTATION.

WE ARE PLEASED TO PROVIDE OUR QUOTATION ON THE MATERIAL DETAILED BELOW.

ITEM	QTY.	DESCRIPTION
		*BEST Warranty in the Industry! Hoffer HO Precision Series (Liquid and Gas) and API Series of Turbine Flowmeters carry a 5-Year Warranty.
2	2	*HOFFER ½" HO PRECISION TURBINE FLOWMETER / SY100 SERIES

RECOMMENDATION IS BASED ON A MAXIMUM OPERATING PRESSURE OF 150 PSIG AND AN AMBIENT OPERATING TEMPERATURE.

MODEL HO½X½-1-10-T-1M-P1SS-SY100

SERVICE FLUID:	FUEL OIL
LINEAR FLOW RANGE:	1.25 TO 9.5 GPM
REPEATABLE FLOW RANGE:	.8 TO 12 GPM
LINEARITY:	+/- 2% OF READING OVER THE LINEAR FLOW RANGE.
REPEATABILITY:	+/-0.5% OF READING OVER THE REPEATABLE FLOW RANGE.
CONSTRUCTION:	316 STAINLESS STEEL WITH 17.4 PH ROTOR.
END FITTING:	1/2" 150 # 316 S.S. RAISED FACE FLANGES PER ANSI.
BEARINGS:	TUNGSTEN CARBIDE SLEEVE TYPE.
MAXIMUM ALLOWABLE PARTICLE SIZE:	.0055" (100 MESH)
PICKUP COIL:	MAGNETIC TYPE.
CALIBRATION:	SUPPLIED WITH TEN POINT WATER CALIBRATION TRACEABLE TO NIST.
FLOW RANGE FLOWMETER WILL BE CALIBRATED OVER: (UNLESS OTHERWISE SPECIFIED)	1 TO 10 GPM

LIST PRICE .... $1782.50 EA
RESELLERS PRICE .... $1515.00 EA

NOTE:
WE ARE UNABLE TO OFFER AN OPTIONAL END FITTING FOR THE SY100 SERIES FLOWMETERS AS REQUESTED.

QUOTATION

HOFFER FLOW CONTROLS, INC.
The Turbine Flowmeter Company™
107 Kitty Hawk Lane • P.O. Box 2145 • Elizabeth City, North Carolina 27906-2145

(252) 331-1997
(800) 628-4584
FAX (252) 331-2886

TO: SEAWORTHY SYSTEMS, INC.
22 MAIN STREET
CENTERBROOK, CT 06409
ATTN: TED DIEHL
TEL: (860)767-9061
FAX: (860)767-1263

REFERENCE:
FUEL OIL

QUOTE NO. 39085 PAGE 3

DATE OCTOBER 13, 1999

FIRM FOR 60 DAYS NET 30 DAYS UPON CREDIT APPROVAL

F.O.B. ELIZABETH CITY, NC 27909

SHIPPING DATE SEE SHIPPING NOTE AT END OF QUOTATION.

WE ARE PLEASED TO PROVIDE OUR QUOTATION ON THE MATERIAL DETAILED BELOW:

ITEM	QTY.	DESCRIPTION
3	2	(FOR USE WITH ITEM 2, 2" FLOWMETER) SIGNAL CONDITIONER / CONVERTER MODEL: ACC34-3-C1-A-X-5-MSE OUTPUT TYPE: 4 TO 20 MA (ISOLATED) INPUT POWER REQUIRED: 115 VAC ENCLOSURE STYLE: NEMA 4 (WALL MOUNT) LIST PRICE .... $1012.00 EA RESELLERS PRICE .... $880.00 EA
4	2	2 CHANNEL FLOWSTAR 2800-A VOLUMETRIC TOTALIZER/FLOW RATE INDICATOR. MODEL 2000-A-3-R2-1-2-M-X-1-HO/LO-ND-MS FEATURES: (* INDICATES STANDARD FEATURES) - 7 DIGIT LCD DISPLAY OF TOTAL IN GALLONS.* - 7 DIGIT LCD DISPLAY OF RATE IN GALLONS/MINUTE. * - 0-5 VDC ANALOG OUTPUT.* - MAGNETIC COIL INPUT SIGNAL ACCEPTED ON CHANNEL 1. - 4 TO 20 MA ANALOG SIGNAL INPUT ACCEPTED ON CHANNEL 2. - RS-232 COMMUNICATION PORT. * - OPEN COLLECTOR SCALED PULSE OUTPUT. (MAXIMUM COUNT SPEED: 33 CPS; PULSE WIDTH: 15 MILLISECONDS, NOT ADJUSTABLE)* - NEMA 4X ENCLOSURE. - HIGH/LOW ALARMS, OPEN COLLECTOR. * - REQUIRES 115 VAC INPUT POWER. * - FACTORY PROGRAMMED AND CONFIGURED AT NO CHARGE WHEN PURCHASED WITH A HOFFER TURBINE FLOWMETER.* - SET AUXILIARY CHANNEL 1, MINUS CHANNEL 2. LIST PRICE .... $1395.00 EA RESELLERS PRICE .... $1255.50 EA

QUOTATION

HOFFER FLOW CONTROLS, INC.
The Turbine Flowmeter Company™

107 Kitty Hawk Lane • P.O. Box 2145 • Elizabeth City, North Carolina 27906-2145

(252) 331-1997
(800) 628-4584
FAX (252) 331-2886

TO SEAWORTHY SYSTEMS, INC.
22 MAIN STREET
CENTERBROOK, CT 06409
ATTN: TED DIEHL
TEL: (860)767-8061
FAX: (860)767-1263

REFERENCE

FUEL OIL

QUOTE NO. 38066 PAGE 4

DATE OCTOBER 13, 1999

FIRM FOR 60 DAYS NET 30 DAYS UPON CREDIT APPROVAL

F.O.B. ELIZABETH CITY, NC 27909

SHIPPING DATE SEE SHIPPING NOTE AT END OF QUOTATION.

WE ARE PLEASED TO PROVIDE OUR QUOTATION ON THE MATERIAL DETAILED BELOW:

ITEM	QTY.	DESCRIPTION
5	2	SIGNAL CABLE ASSEMBLY CONNECT BETWEEN MAGNETIC COIL ON FLOWMETER AND MODEL 2000. 8' SHIELDED LIST PRICE .... $28.00 EA RESELLERS PRICE .... $25.20 EA
6	2	SIGNAL CABLE ASSEMBLY CONNECT BETWEEN FLOWMETER AND SIGNAL CONDITIONER / CONVERTER LIST PRICE .... $28.00 EA RESELLERS PRICE .... $25.20 EA
7	2	SIGNAL CABLE ASSEMBLY CONNECT BETWEEN SIGNAL CONDITIONER / CONVERTER AND MODEL 2000. 8 FT. SHIELDED. LIST PRICE .... $20.00 EA RESELLERS PRICE .... $18.00 EA
8	2	POWER CABLE ASSEMBLY CONNECT BETWEEN POWER SUPPLY AND FLOWSTAR. 8' SHIELDED. LIST PRICE .... $22.50 EA RESELLERS PRICE .... $20.25 EA
9	2	POWER CABLE ASSEMBLY CONNECT BETWEEN POWER SUPPLY AND SIGNAL CONDITION / CONVERTER. LIST PRICE .... $22.50 EA RESELLERS PRICE .... $20.25 EA

QUOTATION

HOFFER FLOW CONTROLS, INC.
The Turbine Flowmeter Company™

107 Kitty Hawk Lane • P.O. Box 2145 • Elizabeth City, North Carolina 27906-2145

(252) 331-1997
(800) 628-4584
FAX (252) 331-2886

TO: SEAWORTHY SYSTEMS, INC.
22 MAIN STREET
CENTERBROOK, CT 06409
ATTN: TED DIEHL
TEL: (860)767-8081
FAX: (860)767-1263

REFERENCE:
FUEL OIL

QUOTE NO 30085 PAGE 5

DATE OCTOBER 13, 1999

FIRM FOR 30 DAYS NET 30 DAYS UPON CREDIT APPROVAL

F.O.B ELIZABETH CITY, NC 27909

SHIPPING DATE SEE SHIPPING NOTE AT END OF QUOTATION.

WE ARE PLEASED TO PROVIDE OUR QUOTATION ON THE MATERIAL DETAILED BELOW.

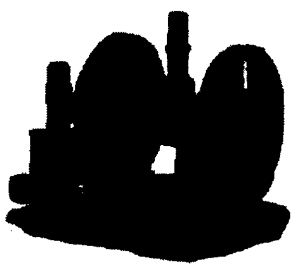
ITEM	QTY.	DESCRIPTION
		NOTE: FLOWMETERS ARE OF NAVY DESIGN. SIMILAR SY100 SERIES FLOWMETERS HAVE PREVIOUSLY PASSED SHOCK & VIBRATION TESTING.
		THE MODEL 2000 FLOWSTAR TOTALIZER / INDICATOR IS NOT SHOCK & VIBRATION PROOF. WE OFFER A MODEL 47-SY100 THAT IS. UNFORTUNATELY IT DOES NOT OFFER 2 CHANNELS FOR UP / DOWN COUNTING.
		Linda Markham LINDA MARKHAM/PRODUCT SALES lmarkham@hofferflow.com
		SHIPPING NOTE: 3 TO 5 WEEKS, A.R.O. OR BETTER. CONSULT FACTORY FOR SHIPPING IMPROVEMENT. MANY PRODUCTS ARE AVAILABLE FROM ESP STOCK PROGRAM OR ON AN EXPEDITED BASIS.
		"HOFFER FLOW CONTROLS NOW ACCEPTS CREDIT CARDS FOR PAYMENT. WE ACCEPT VISA, AMERICAN EXPRESS, AND MASTERCARD. ADD 4% HANDLING FEE TO THE NET ORDER AMOUNT IF PAYMENT WILL BE MADE VIA CREDIT CARD."

HOFFER FLOW CONTROLS, INC.
The Turbine Flowmeter Company

Turbine Flowmeters by Hoffer : Accurate, Versatile and Econom

Turbine flowmeters continue to be the most common way to measure flow electronically in a wide ran; industries. A review of the advantages turbine flowmeters have to offer provides insight into the grow popularity of this versatile flow transducer.

Hoffer turbine flowmeters offer:



- Wide flow rangeability in liquids and gases
- Outstanding accuracy at low cost
- Wide range of construction materials that permit application in many process fluids or gases
- Simple, durable, field repairable construction
- Flexibility in associated electronic readout devices flow rate indication, flow totalization, flow control computer interface
- Wide variety of process connections
- Operation over a wide range of temperature and pr

To summarize, Hoffer turbine flowmeters are accurate, versatile, and an economical means of measuring

Three different flowmeter series are presented in our guide, applicable to low, medium and high flow rat They include; The Hoffer HO Series of standard turbine flowmeters, for liquids and gases, the MF Serie: Mini- Flowmeters, for liquids, and the Hoffer HP Series of insertion flowmeters, for liquids and gases. T three distinct Hoffer series offer the capability of measuring a wide range of flow rates over equally wide ranges of temperatures, pressures and other variables.

For information, or send e-mail to : info@hofferflow.com
Please include complete e-mail/snail-mail address and Company name.

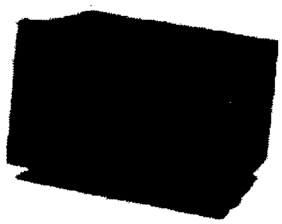
Hoffer Flow Controls, Inc.
PO 2145 , Elizabeth City , NC 27906
1-800-628-4584 Nationwide

HOFFER FLOW CONTROLS, INC.
The Turbine Flowmeter Company

FLOW STAR SERIES :: GENERAL DESCRIPTION

The Model 2000 is a microprocessor based volumetric flow rate indicator/totalizer that provides local di and transmits flow data for control capability. The unit is part of a cost effective familiy of flow products designed to accept inputs from pulse producing or analog producing flowmeters.

In addition to the Model 2000, the **Flowstar** series includes additional software packages to support the following functions:



- **Model 2001** Temperature Compensated Mass F Computer for Liquids
- **Model 2002** Compressed Natural Gas Flow Co compliant with AGA report #8 (Supercompress
- **Model 2003** Multi-Curve Process Batch Contro
- **Model 2005** Temperature/Pressure Compensate Mass Flow Computer for Liquids
- **Model 2006** Temperature/Pressure Compensate Mass Flow Computer for Gases
- **Model 2007** Temperature/Pressure Compensate Mass/Volumetric Batch Controller for Liquids

The unit is factory programmed to display either English or Metric units when purchased with a Hoffer T Flowmeter. This feature should save the user numerous hours of setup time that is associated with other microprocessor based units available in the marketplace. Programming is done through the front panel keyboard, as well as through the two way RS-232 or RS-422/RS-485 multi-drop communications port.

Flowstar offers from single to four channel input capability. Multiple channel units are available to acce flowmeter inputs simultaneously. Alternately, Flowstar may be configured to support a dual channel ma installation. It may be used with two coil flowmeters (quadrature) for detection of flow direction.

For information, or send e-mail to : info@hofferflow.com
Please include complete e-mail/snail-mail address and Company name.

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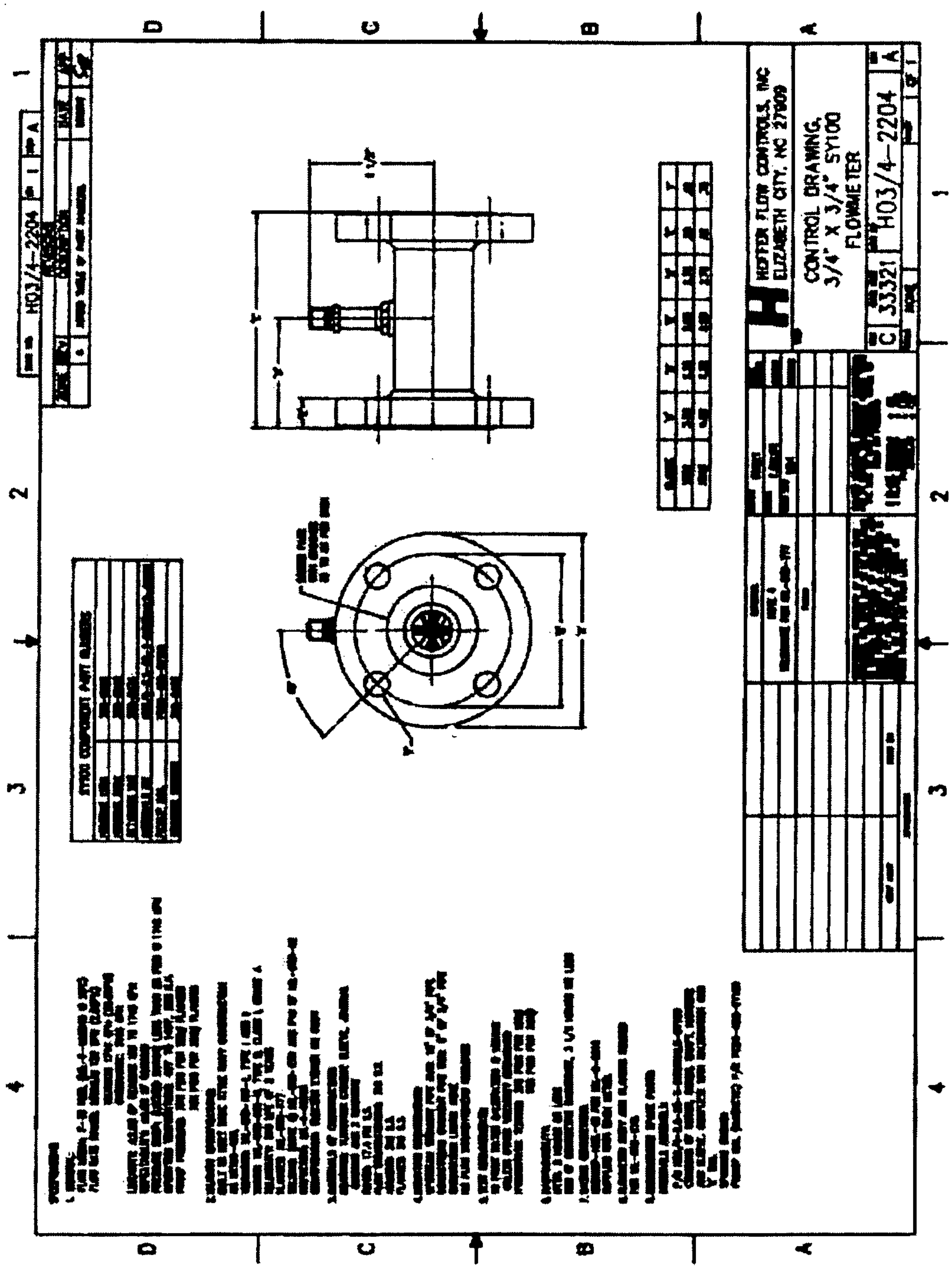
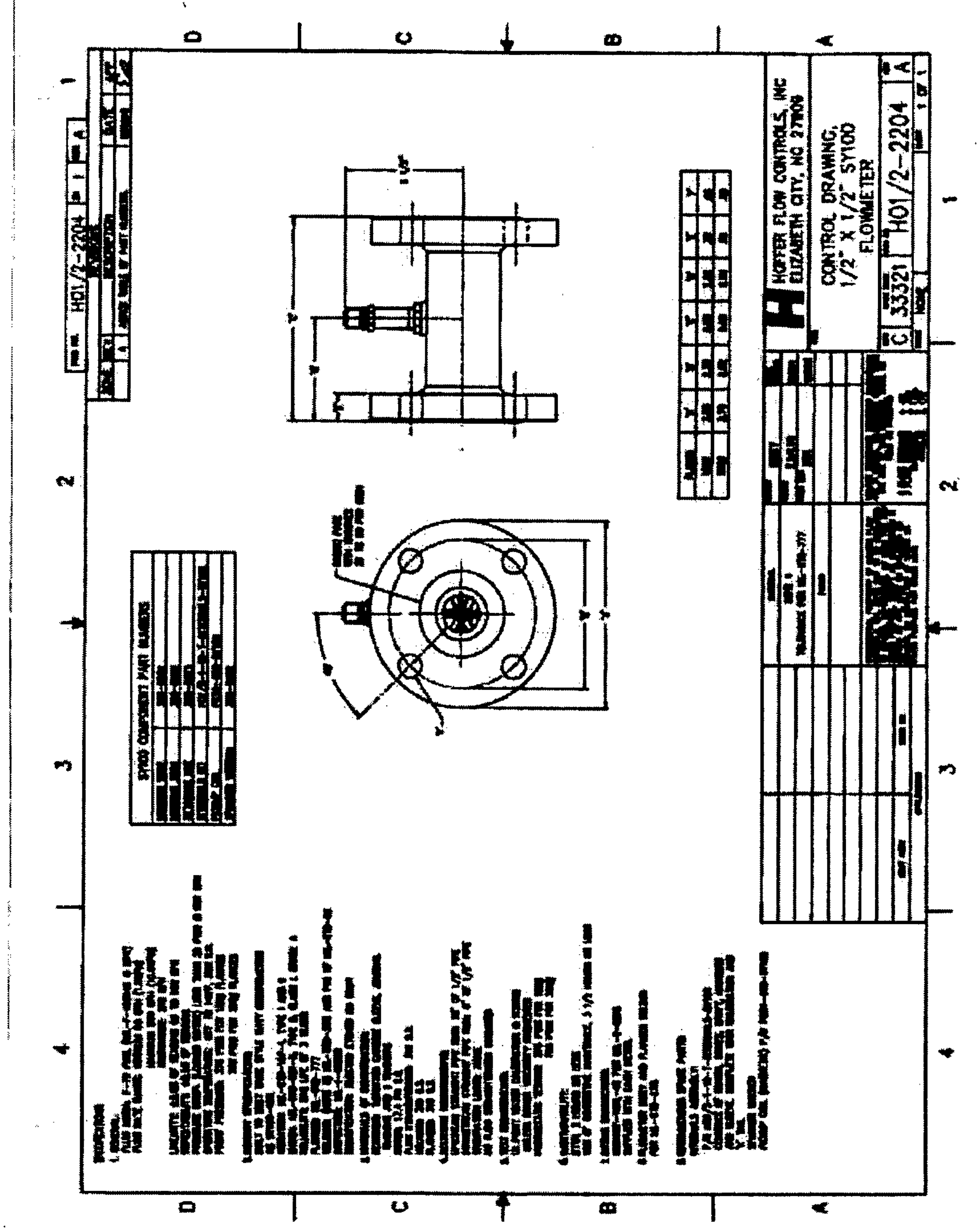
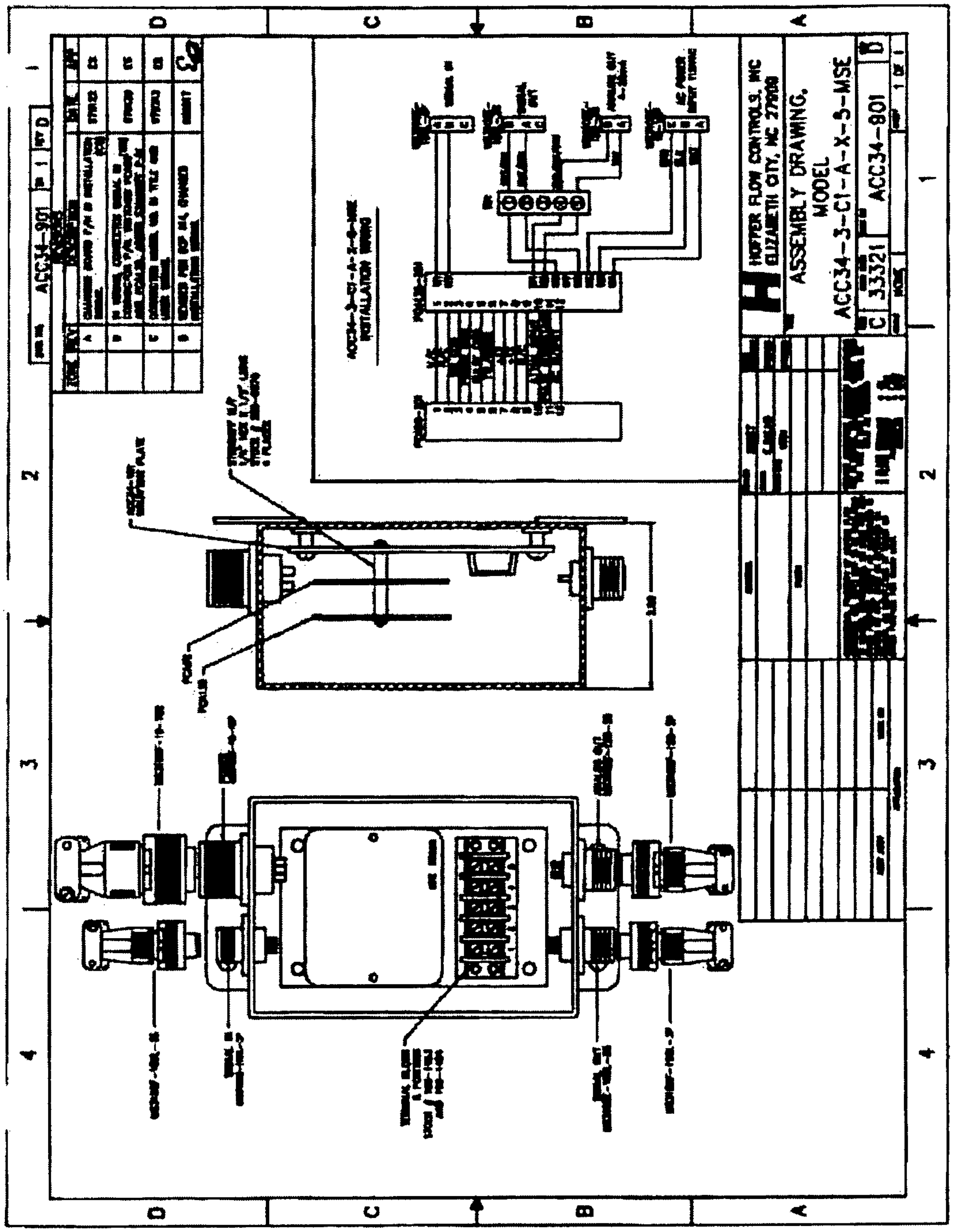
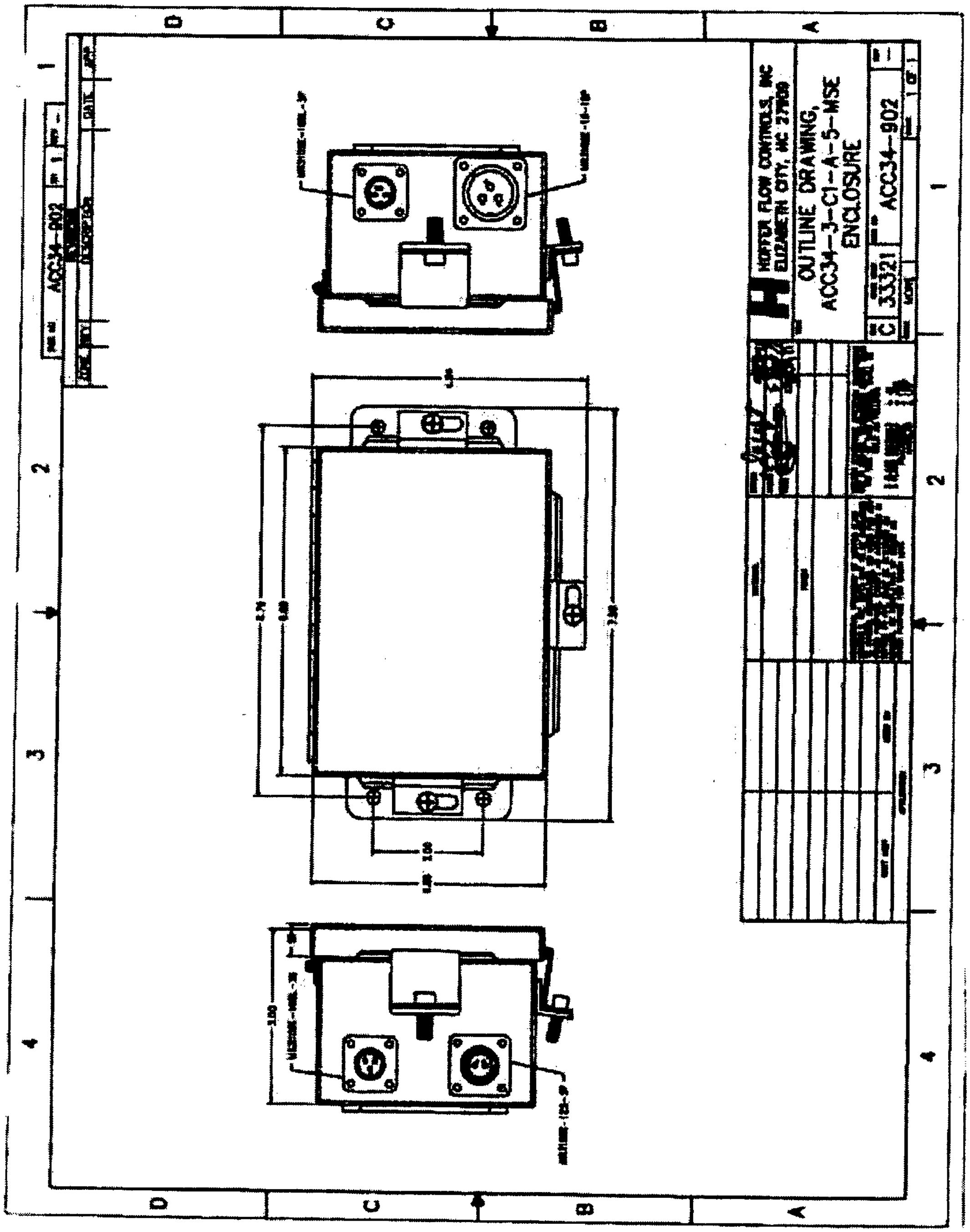

HOFFER FLOW CONTROLS, INC
ELIZABETH CITY, NC 27909
CONTROL DRAWING,
3/4" X 3/4" SY100
FLOWMETER
C
33321
H03/4-2204
A
H03/4-2204
1 1/2"


HOFFER FLOW CONTROLS, INC
ELIZABETH CITY, NC 27909
CONTROL DRAWING,
1/2" X 1/2" SY100
FLOWMETER
C
33321
HO1/2-2204
A
SY100 COMPONENT PART NUMBERS


HOFFER FLOW CONTROLS, INC
ELIZABETH CITY, NC 27909
ASSEMBLY DRAWING,
MODEL
ACC34-3-C1-A-X-5-MSE
C 33321 ACC34-801
ACC34-3-C1-A-X-5-MSE
INSTALLATION WIRING
ACC34-901


ACC34-902
HOFFER FLOW CONTROLS, INC
ELIZABETH CITY, NC 27909
OUTLINE DRAWING,
ACC34-3-C1-A-5-MSE
ENCLOSURE
C
33321
ACC34-902

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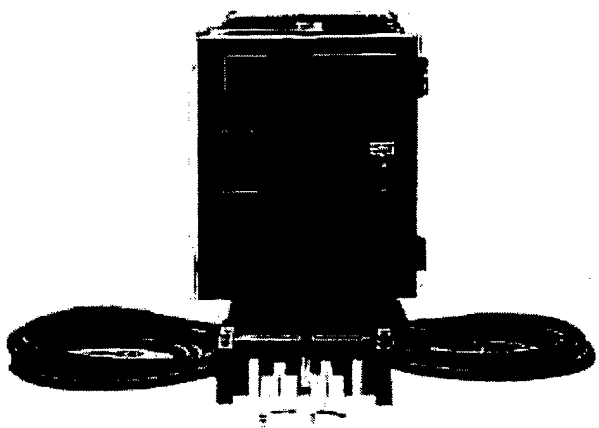
APPENDIX E. TORQUE METER AND ENGINE ANALYZER TECHNICAL LITERATURE

THE DIGITAL TORQUE METER SYSTEM

Manufactured by IC³



The Digital Torque Meter (DTM) System measures shaft horsepower and RPM by employing fiber optics to detect the twist in a rotating shaft. Real time measurement at all speeds is accomplished without signal conversion by processing the digital outputs from two stationary sensors as interrupters, mounted on the shaft, pass through a beam of visible light once per revolution. No drilling, welding, or machining is required for installation. Calibration is accomplished at start-up by programmable means, without the need for any additional test equipment and can be easily verified by operating personnel. The DTM System consists of an electronics display/enclosure, fiber optic cables, stationary sensors (orange) and interrupters (white) as shown to the left.

- **COMPETITIVELY PRICED**
- FIBER OPTIC DIGITAL TECHNOLOGY
- ACCURATE, REPEATABLE, RELIABLE
- SIMPLIFIED INSTALLATION & CALIBRATION
- 24 HOUR TECHNICAL SUPPORT LINE

- DTM SYSTEM INCLUDES

  1) NEMA 4 electronics enclosure
  2) Two sensors and two interrupters per shaft
  3) One set of fiber optic cables
  4) Installation kit
  5) Operating and calibration documentation

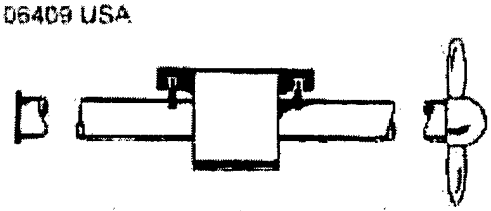
- OPTIONAL FEATURES AND SERVICES

  1) Multiple shaft/area installations
  2) Remote SHP, RPM and torque displays
  3) Various outputs (RS232 ASCII, 4-20 mA, 20 mA current loop, 0-5 VDC, etc.)
  4) Installation, start-up and training

Distributed by:

FCS, Inc.
22 Main St
Centerbrook, CT
06409 USA

Tel (860) 767-3095
Fax (860) 767-1263



Typical installation on a line shaft bearing housing

Detail of actual sensor & interrupter

The MALIN 2000

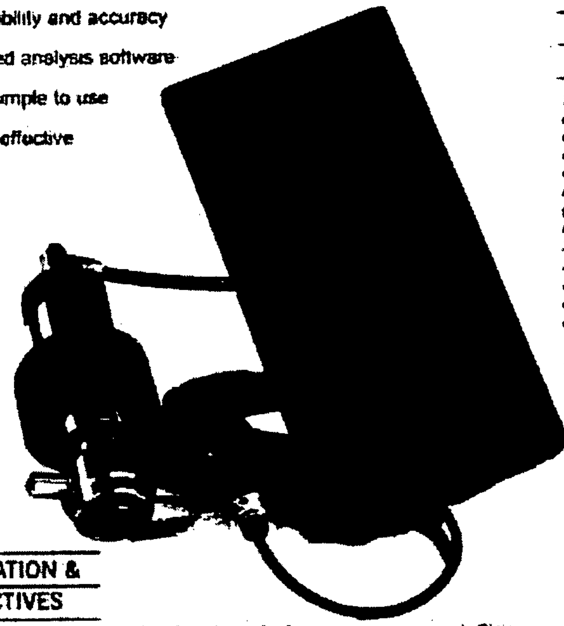
Entry-level product based on the award winning Malin 3000

Proven reliability and accuracy

Sophisticated analysis software

Extremely simple to use

Highly cost effective



DIESEL

ENGINE

PERFORMANCE

MONITORING

SYSTEMS

The original Malin 3000 was introduced in 199? in response to a real demand for a portable and practical system for the accurate monitoring of diesel engines. It was greeted with great acclaim, a fact confirmed by the presentation of a SEATRADE Award in [illegible] Since then it has been continued & upgraded and inevitably has attracted its share of imitators but nevertheless has always provided the benchmark others only strive towards

The MALIN 2000 is the new entry-level version which provides many of the features of the MALIN 3000 at a cost-effective price

APPLICATION & OBJECTIVES

The MALIN 2000 is a portable, robust system that accurately measures cylinder pressure in relation to crankshaft angle in two or four stroke diesel engines (40-1600 r.p.m.)

It provides clear concise information that enables the engineer to diagnose faults and predict potential problems before they result in costly overhaul and possible breakdown. It can detect changes due to fuel quality and confirm the result of any adjustment. Data stored by downloading to a PC can, after a period, present a detailed picture of engine performance, cylinder by cylinder. Long term maintenance schedules can be devised based on actual working loads of individual engines. In short engines can be returned to, and maintained at optimum performance. The resultant saving in reduced fuel consumption improved efficiency and reduced downtime and predictability cannot be overstated

The Indicator with its PC SOFTWARE gives immediate checks on

Engine Condition

Relative Power Output of each cylinder

Mechanical Balance

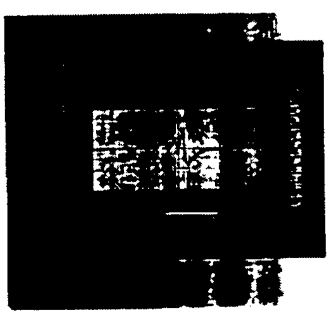
Diagnostics from detailed view of pressure diagrams

Fuel Injection Timing and Combustion Performance

Thermal Efficiency and Economy

Monitoring of engine performance and degradation over time

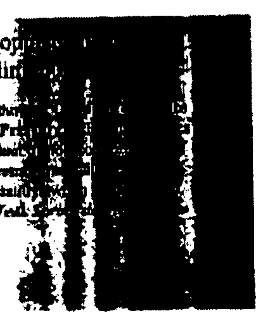
Long term maintenance planning



The Malin 2000 indicator has the same sop[...] software as its big brother the Malin [...]

Set-up is quickly completed on a single screen where all the engine details are entered and sent via the RS232 interface to the MALIN 2000 Data can be quickly downloaded within minutes and stored for future reference

The software the[...] of Change of Pr[...] an instant reading[...] and rate of press[...] zoom in or instantly[...] PV trace, or Weib[...]



DIESEL
ENGINE
PERFORMANCE
MONITORING
SYSTEMS

OPERATION

The System has been designed for ease of use and includes a simple yet comprehensive Windows software program.
The engine bore, stroke and con rod dimensions are downloaded from the PC database. Other information such as engine name, cylinder number, exhaust temperature, fuel rack, VIT and turbo boost can also be input.
Production of a full analysis of each cylinder requires connection of the pressure transducer to a standard cylinder indicator port and attachment of the flywheel sensor. This initiates the data acquisition procedure and measures engine speed.

INSTRUMENT DATA DISPLAY

A simplified user interface provides step by step instructions on an easy to read 16 character x 2 line backlit alpha-numeric display.
As well as logging and storing complete traces the Malin 2000 can be used to directly indicate magnitude and spread of Pmax over many engine cycles.

SYSTEM COMPONENTS

THE INDICATOR
Truly portable at only 500 grams, it is powered by internal nickel cadmium rechargeable batteries, which give a minimum of eight hours continuous operation before requiring a recharge.
The instrument is robustly constructed with a fully sealed fuel resistant case and fascia panel with push button controls. Top connections include sockets for the transducer, flywheel sensor and battery charger (all supplied with the system) and an RS232 port for communicating with a PC.

THE TRANSDUCER
This is the key element of the system because any measurement is only as accurate as the sensor allows.
Developed specifically to monitor cylinder pressure, Dive Time have opted for a proven and reliable system. The transducer is housed in a stainless steel body with finned heatsink. No special extra cooling is required.
Connection is made to the engine with a tapered shank and locknut designed to fit a standard indicator port.
A heat resistant connecting lead with a choice of straight or 90° connectors is provided to link the transducer to the analyser. The lead does not form part of the calibration so, should it become damaged, only a simple replacement is necessary.

FLYWHEEL SENSOR
The pulse from the flywheel sensor initiates the acquisition procedure, indicates the position of the crankshaft and measures engine speed. Connecting and extension leads are provided with the system.

PRODUCT FEATURES

THE ANALYSER
RPM Range: 40-1600 rpm
Accuracy on Pressure Reading: +/-1%
Store Capacity: 20 cylinders
Sample Interval: ≤0.2 degrees
Analyser Case: Fuel Resistant ABS
Power Source: 6 x 1.2V 1.4 A/h rechargeable Ni-Cad C-Cells
Operating Time: 8 hours from full charge
Serial Comms: RS232
Display: 16 x 2 alphanumeric backlit.

TRANSDUCER
Frequency Response: 5kHz
Excitation Voltage: 5V DC
Linearity and Hysteresis: +/-1%
Inbuilt Temperature Sensor

FLYWHEEL SENSOR
Type: Hall effect
Excitation Voltage: 5V DC
Protection: IP67
Operating Distance: 1-3mm

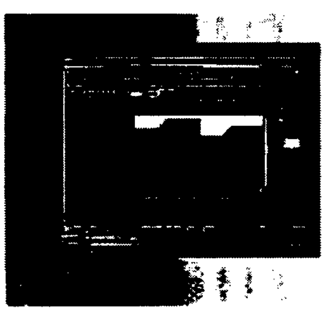
UNIVERSAL CHARGER
Input: nominal 90 - 250V AC 50/60Hz
Output: 12V DC

DIVE TIME
SYSTEMS LIMITED

Represented by

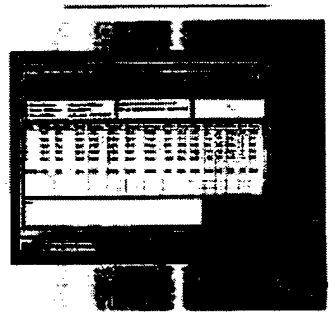
FCS

22 Main Street
Centerbrook, CT 06409
(860) 767-3095
Fax: (860) 767-1365



The software shows **Engine Balance** of all parameters - these can be shown at any angle or at the deviation or percent deviation from the mean.

Quickly create an **Engine Data Summary** for reports, then add comment notes. Show overlays and trends at the click of a button.



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APPENDIX F. MISSION PROFILE DATA AND CLASS AOPS SUMMARIES

F.1 Class vs. Mission Profiles

Using operating hours obtained from the most recent available Class Abstracts of Operation, AOPS, representative mission profiles were developed for the WMEC 210', WMEC 270', and WHEC 378' (Fiscal Years 1993, 94, 95, 96 and 97) and WLB 225' (Fiscal Years 1996, 1997, 1998 and the first three quarters of 1999). For the purposes of this analysis, all of the varying mission types reported in the Class AOPS reviewed were assigned to one of the seven general mission categories listed and briefly described below.

- DRUG INTERDICTION: Air and surface enforcement of laws and treaties (ELT).
- FISHERIES PATROL: Domestic and foreign ELT.
- IMMIGRATION INTERDICTION: Migrant ELT.
- MILITARY /COOPERATIVE EXERCISES: Federal, state and local cooperative exercises, international affairs, military exercises, peace and wartime military operations, and military port security.
- SEARCH AND RESCUE (SAR): Search and rescue operations.
- TRAINING OPERATIONS: Cadet and officer training, military operations and refresher training, and U.S. Coast Guard reserve operations.
- OTHER: Various mission such as polar operations, domestic ice-breaking, port safety and security, public affairs, recreational boat safety and marine inspections, aids to navigation and radar navigation training, bridge administration, marine environmental protection (MARPOL, operations and enforcement), marine science activities, marine sanctuary patrols, other ELT and miscellaneous operations.

In the following paragraphs, it will be noted that a significant portion of the WLB 225' Class operating profile (60%) has been assigned to the OTHER mission category. This segment of operating time is comprised of buoy tending activities, a primary mission that is unique to this cutter Class when compared to the mission requirements of the three other Classes addressed herein.

Figure F-1 presents, in histogram format, a breakdown of mission profiles for the WMEC 210', WLB 225', WMEC 270' and WHEC 378' Classes as a percentage of total annual average per

cutter underway operating hours derived from the Class AOPS data discussed previously. Table F-1 summarizes this information in matrix format.

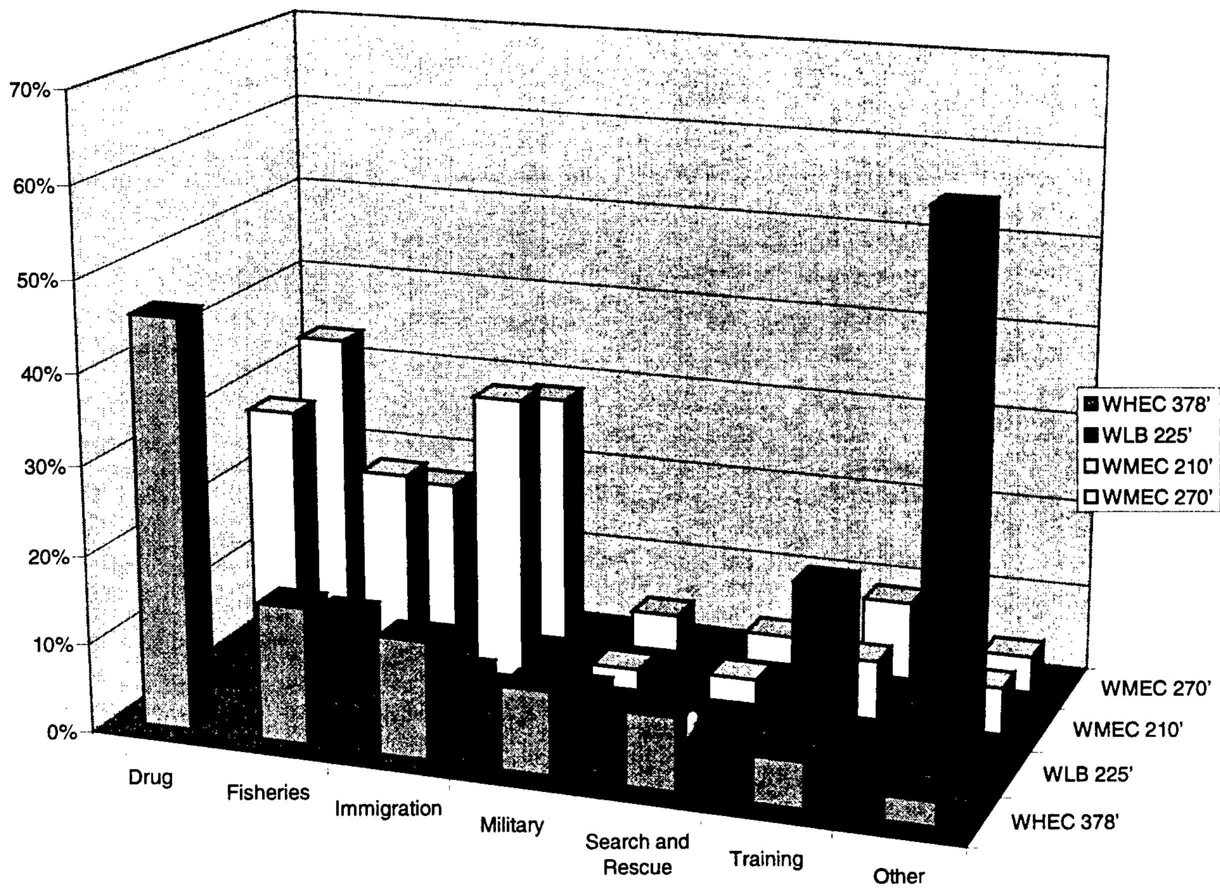

Figure F-1. Class vs. mission profile summary.

Figures F-2 through F-5 present this data individually for each of the four classes, along with the annual average underway hours spent during operations in each mission category.

Table F-1. Class vs. mission, hours per year.

	WMEC 210'		WLB 225'		WMEC 270'		WHEC 378'	
Drug	759	(28%)	0	(0%)	1,104	(33%)	1,449	(46%)
Fisheries	600	(22%)	138	(10%)	573	(17%)	487	(15%)
Immigration	865	(32%)	66	(5%)	953	(29%)	419	(13%)
Military	64	(2%)	60	(4%)	143	(4%)	298	(9%)
Search and Rescue	77	(3%)	11	(1%)	111	(3%)	261	(8%)
Training	179	(7%)	271	(20%)	296	(9%)	164	(5%)
Other	140	(5%)	834	(60%)	138	(4%)	86	(3%)
Total	2,684	(100%)	1,379	(100%)	3,317	(100%)	3,163	(100%)

In addition to underway operating hours and mission data, the Class AOPS reviewed as part of this effort also included a record of annual in-port (not underway) hours for each cutter with its ship's service electrical power generation and distribution system, and when applicable, its auxiliary boiler in operation. Average annual hours of in-port operation are summarized below for each class.

Class	**In Port Hours/Year**
WMEC 210'	314
WLB 225'	625
WMEC 270'	327
WHEC 378'	562

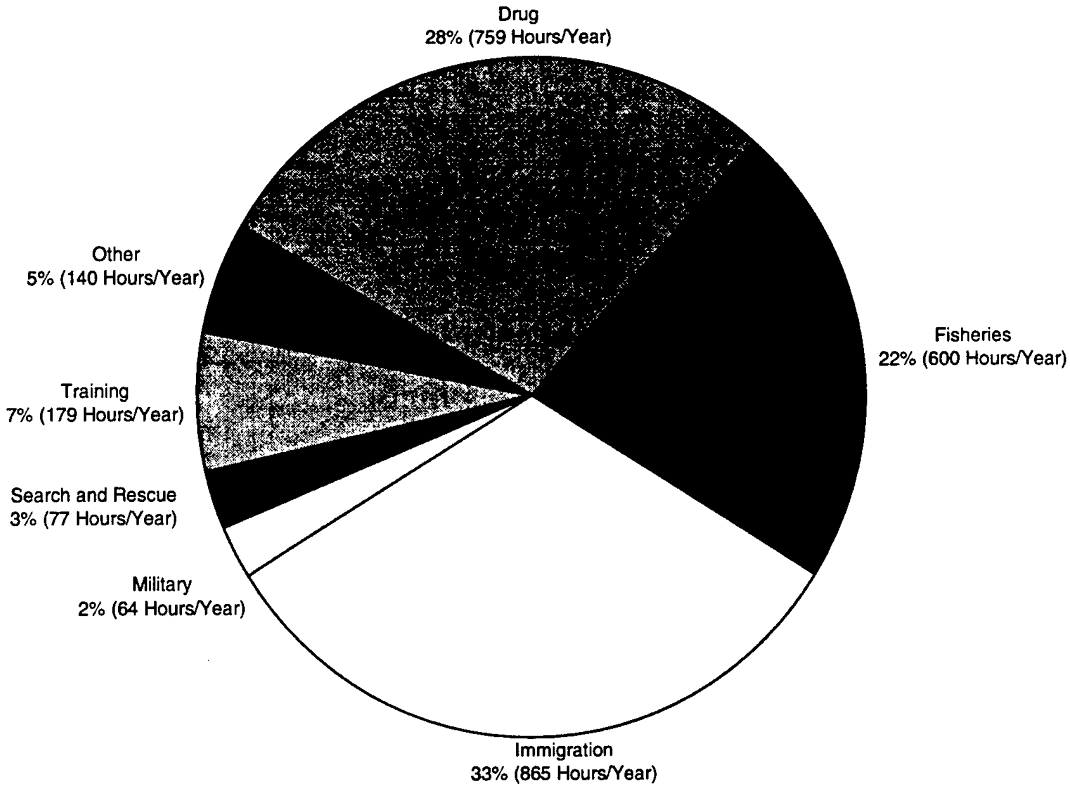

Figure F-2. WMEC 210' Class average mission profile.

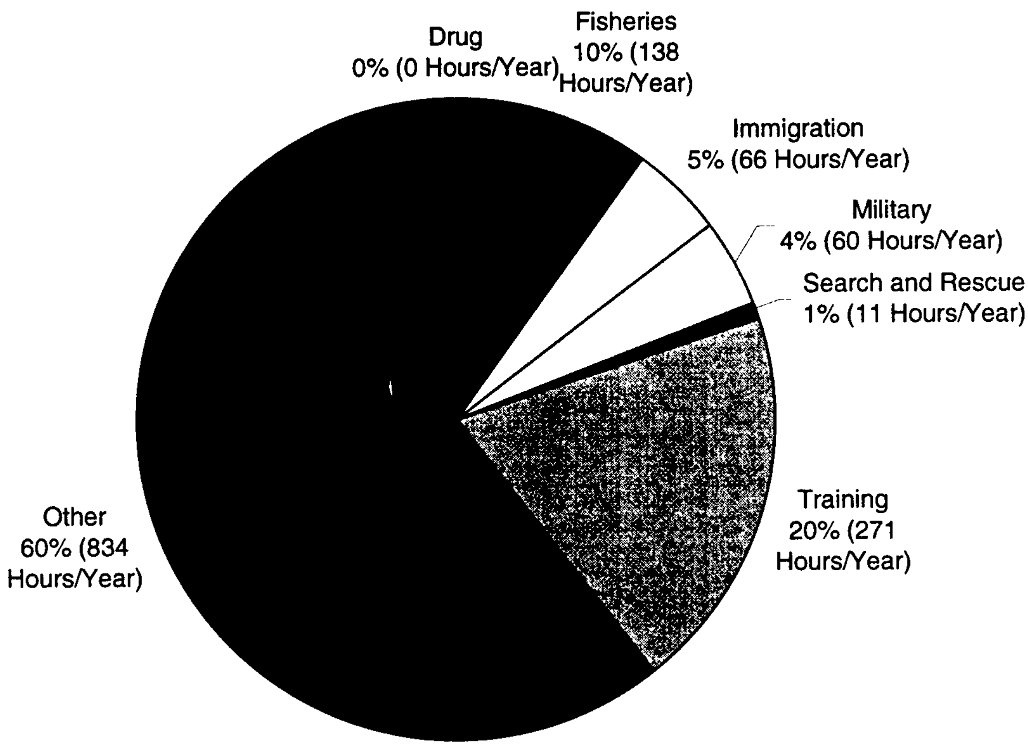

Figure F-3. WLB 225' Class average mission profile.

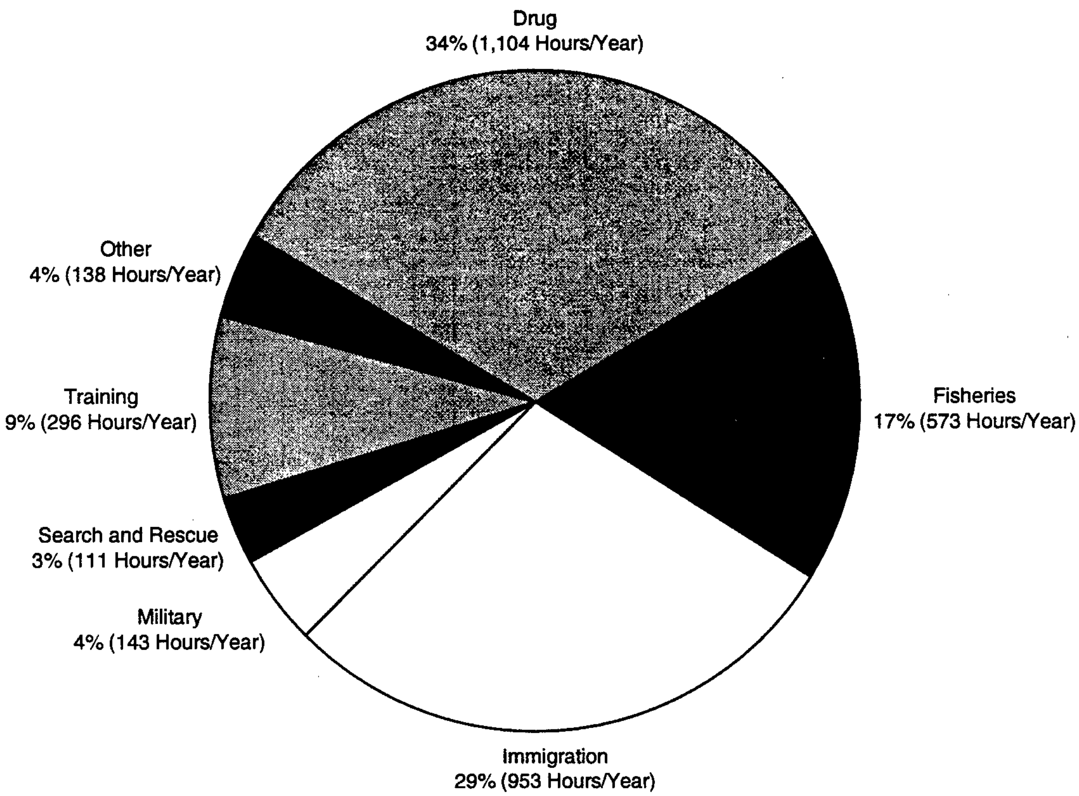

Figure F-4. WMEC 270' Class average mission profile.

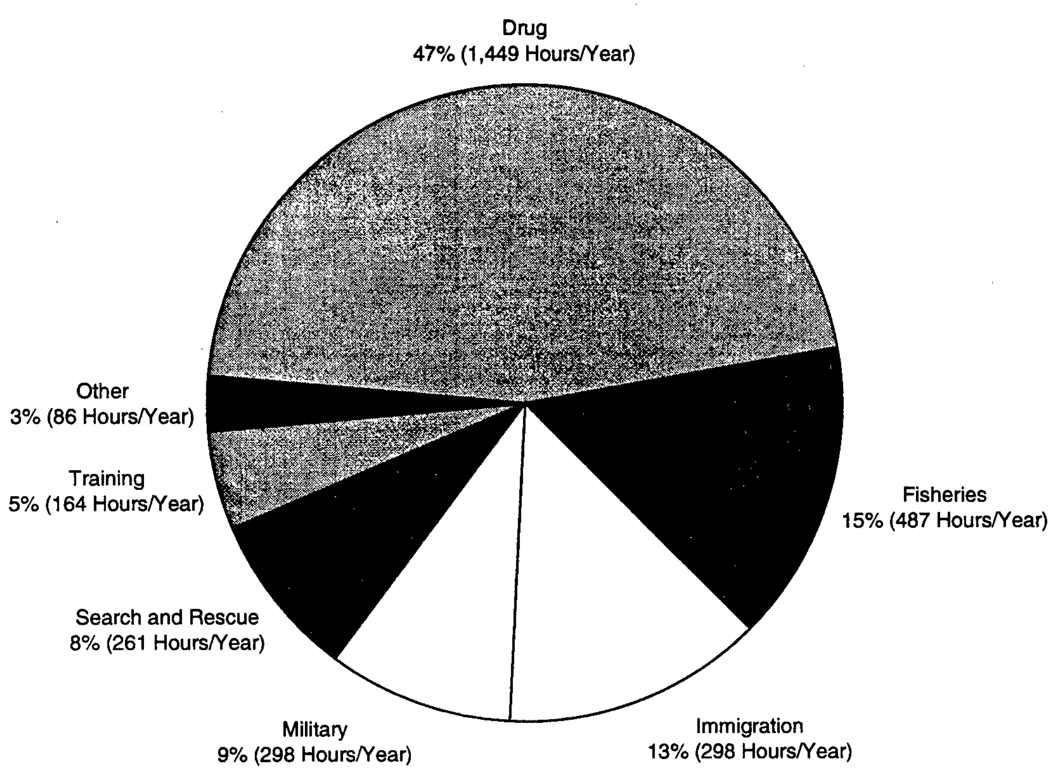

Figure F-5. WHEC 378' Class average mission profile.

F.2 District vs. Mission Profiles

The AOPS on which the previously described Class mission profiles are based also contained detailed information with regard to the district(s) in which each mission was completed. This data was extracted for the following 11 districts.

CGD01 - Boston, Massachusetts
CGD05 - Portsmouth, Virginia
CGD07 - Miami, Florida
CGD08 - New Orleans, Louisiana
CGD09 - Cleveland, Ohio
CGD11 - Alameda, California
CGD13 - Seattle, Washington
CGD14 - Honolulu, Hawaii
CGD17 - Juneau, Alaska
GL - Global
HQ - Headquarters

From the available information representative overviews of the time spent by each Class in each district and the relative distribution of missions carried out in each district were also developed (For the classes addressed by this report, no data was found for District CGD02, while only two hours of operating data for District HQ were retrieved from the AOPS).

Figure F-6 presents the relative distribution of underway operating time spent by each cutter Class in each district, in graphic format, while Table F-2 presents this information in matrix format. Similarly, Figure F-7 presents, in graphic format, the relative distribution of the combined underway time spent annually in each mission category in each district by the WMEC 210', WLB 225', WMEC 270' and WHEC 378' Class cutters. Table F-3 presents this data in matrix format.

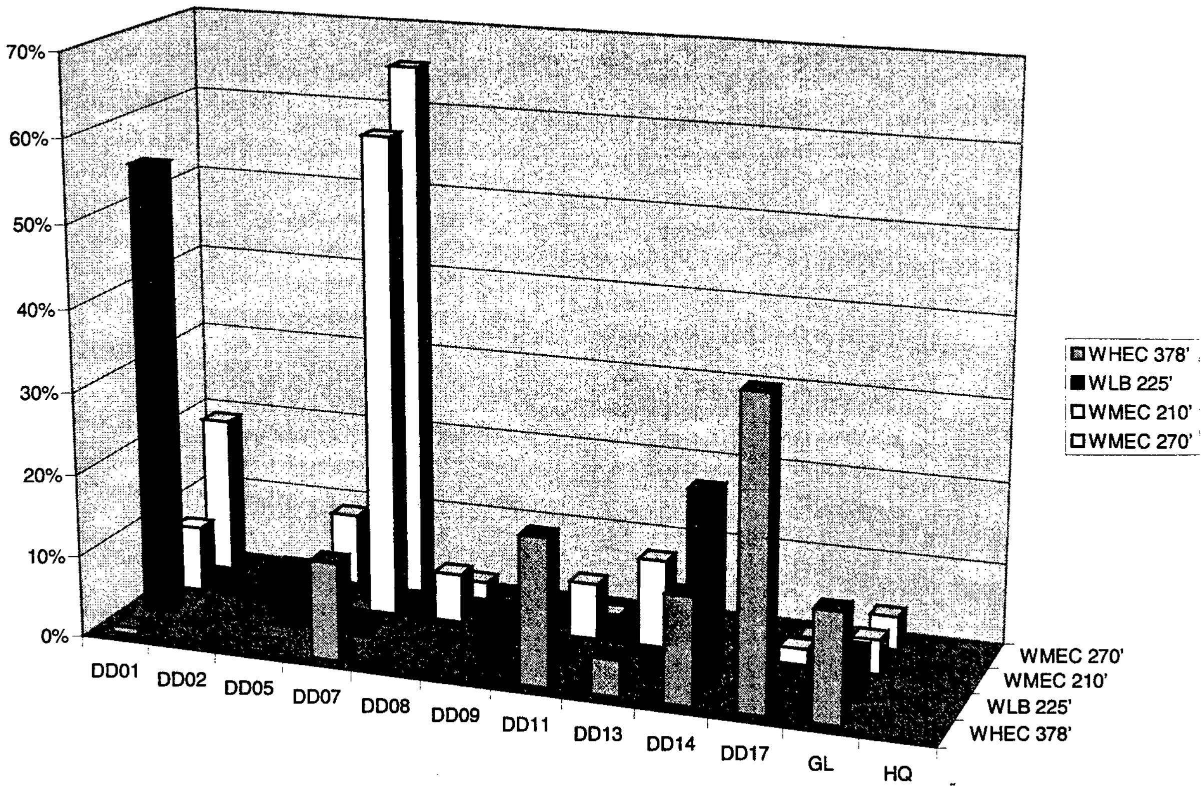

Figure F-6. District vs. class annual operating profile.

Table F-2. Distribution of annual operating profile by district and class, hours/year (%).

	WHEC 378'		WLB 225'		WMEC 210'		WMEC 270'	
CGD01	22	(1%)	760	(55%)	264	(8%)	607	(19%)
CGD05	14	(1%)	104	(8%)	128	(4%)	280	(9%)
CGD07	322	(12%)	28	(2%)	1,945	(59%)	2,068	(65%)
CGD08	0	(0%)	0	(0%)	198	(6%)	68	(2%)
CGD09	0	(0%)	75	(5%)	0	(0%)	3	(0%)
CGD11	484	(18%)	20	(1%)	225	(7%)	2	(0%)
CGD13	121	(5%)	0	(0%)	354	(11%)	0	(0%)
CGD14	353	(13%)	314	(23%)	0	(0%)	0	(0%)
CGD17	1,006	(37%)	0	(0%)	65	(2%)	7	(0%)
GL	362	(13%)	78	(6%)	138	(4%)	128	(4%)
HQ	0	(0%)	0	(0%)	0	(0%)	0	(0%)
Total	2,684	(100%)	1,379	(100%)	3,317	(100%)	3,163	(100%)

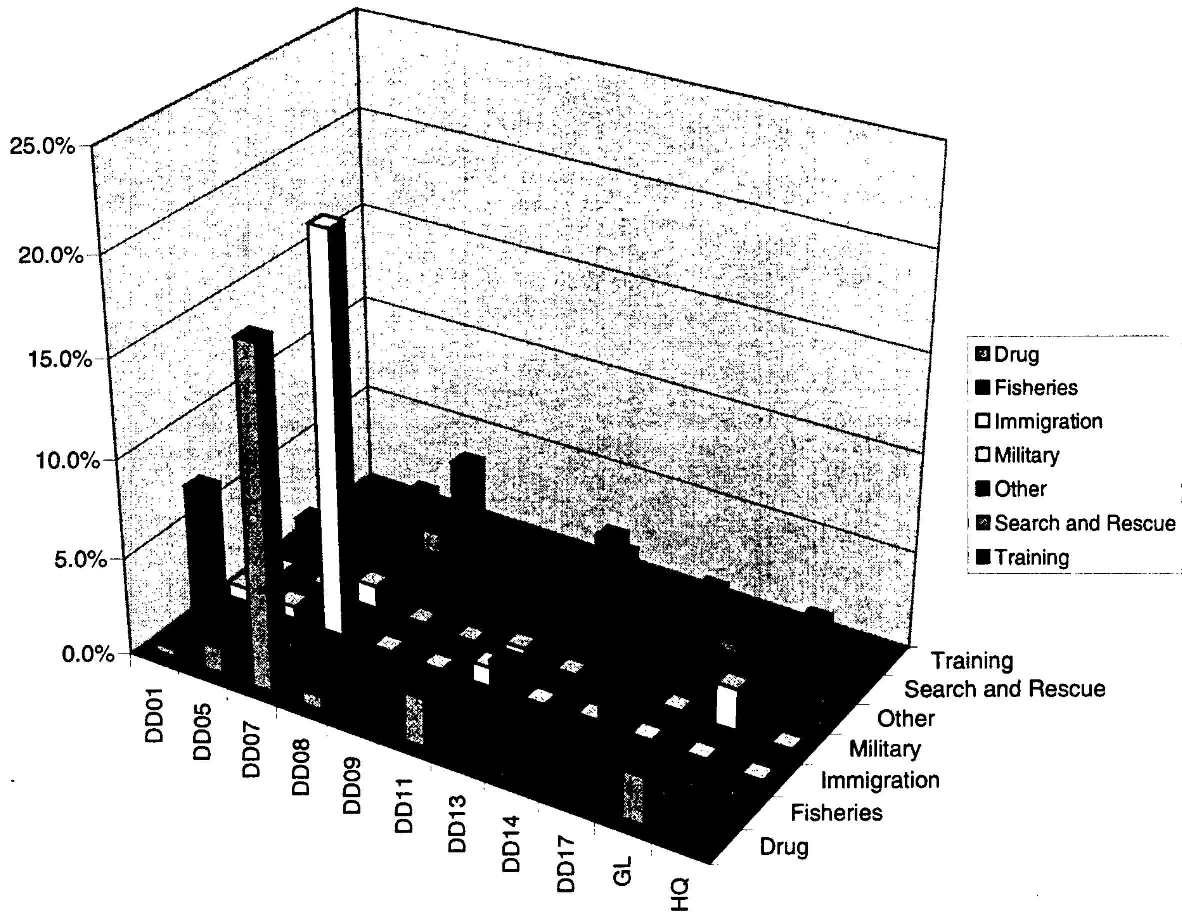

Figure F-7. District vs. mission annual distribution for combined classes.

Table F-3. Distribution of district vs. mission operating hours for combined classes, hours/year (%).

	Drug	Fisheries	Immigration	Military	Search & Rescue	Training	Other
CGD01	2,750 (0.4%)	44,805 (7.2%)	4,388 (0.7%)	842 (0.1%)	3,377 (0.5%)	2,906 (0.5%)	8,770 (1.4%)
CGD05	8,522 (1.4%)	3,233 (0.5%)	3,970 (0.6%)	1,392 (0.2%)	603 (0.1%)	6,241 (1.0%)	5,045 (0.8%)
CGD07	108,344 (17.4%)	2,012 (0.3%)	127,716 (20.5%)	7,277 (1.2%)	7,459 (1.2%)	21,347 (3.4%)	7,960 (1.3%)
CGD08	4,555 (0.7%)	7,505 (1.2%)	362 (0.1%)	455 (0.1%)	708 (0.1%)	1,549 (0.2%)	1,527 (0.2%)
CGD09	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	3 (0.0%)	380 (0.1%)	723 (0.1%)
CGD11	15,955 (2.6%)	6,377 (1.0%)	6,392 (1.0%)	3,405 (0.5%)	583 (0.1%)	12,082 (1.9%)	3,463 (0.6%)
CGD13	1,492 (0.2%)	22,400 (3.6%)	166 (0.0%)	351 (0.1%)	994 (0.2%)	2,260 (0.4%)	2,378 (0.4%)
CGD14	627 (0.1%)	13,652 (2.2%)	1,093 (0.2%)	2,788 (0.4%)	810 (0.1%)	5,475 (0.9%)	4,186 (0.7%)
CGD17	49 (0.0%)	66,579 (10.7%)	659 (0.1%)	413 (0.1%)	3,260 (0.5%)	2,185 (0.4%)	2,381 (0.4%)
GL	15,638 (2.5%)	4,193 (0.7%)	676 (0.1%)	13,539 (2.2%)	475 (0.1%)	6,495 (1.0%)	2,612 (0.4%)
HQ	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	2 (0.0%)	0 (0.0%)
Total	157,932 (25.4%)	170,756 (27.4%)	145,422 (23.3%)	30,462 (4.9%)	18,272 (2.9%)	60,922 (9.8%)	39,045 (6.3%)

CUTTER QUARTERLY EMPLOYMENT - SUMMARY BY RESOURCE

CUTTER
WMEC210

	EMPLOYMENT	MISSN	EMPHRS	DD01	DD02	DD05	DD07	DD08	DD09	DD11	DD13	DD14	DD17	GL	HQ	Sum	IN-O
Other	A TO N	1	16.2	1.2	0	0	0	0.4	0	9.4	2.2	0	0	3	0	16.2	0
Other	BRIDGE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Training	CADET/OC	7.4	4672.4	0	0	0	15.2	15.4	0	0	0	0	0	0	0	30.6	9.6
Military	COOP-FED	1.8	31	0.8	0	0	29.6	0	0	0	0.4	0	0	0	0	30.8	0
Military	COOP-LOCAL	0.6	5.8	0	0	0	0.4	3	0	0	0	0	0	0	0	3.4	0
Military	COOP-STATE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other	DOM ICE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Drug	ELT DRUGS-AIR	0.4	3.4	0	0	0	3.4	0	0	0	0	0	0	0	0	3.4	0
Drug	ELT DRUGS-SURF	55.6	18706.2	39	0	209.6	8777.8	760.6	0	1010.8	155.2	0	0	434.2	0	11387.2	238.2
Fisheries	ELT FISH-DOM	26.4	10060.8	2671.8	0	237.8	157.4	978.4	0	488.4	3506	0	731.2	126	0	8897	191.4
Fisheries	ELT FISH-FOR	1.4	112.2	0	0	0	30.4	44.6	0	0	0	0	22.8	0	0	97.8	0.8
Immigration	ELT MIGRANT	45.8	18072.2	203.4	0	184.2	11857.2	57	0	537.8	18.4	0	0	118	0	12976	402.2
Other	ELT OTHER	2.4	214.2	0	0	0	14	5.8	0	70.2	28.6	0	0	25	0	143.6	10
Other	ELT SANCTS	12.6	410	0	0	0.4	8.2	0.6	0	19.6	119.6	0	0	0	0	148.4	3.8
Military	INTNATL AFFAIRS	10	1378.4	4.8	0	0	348.6	40	0	81	22.2	0	4.6	355.4	0	856.6	365.6
Other	MARINE INSP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other	MEP ENFORCE	2.2	989.4	0	0	0	3.4	2	0	0	1.4	0	0	0	0	6.8	0.8
Other	MEP MARPOL	1.2	121	0	0	0	2	1.8	0	0	0	0	0	0	0	3.8	0
Other	MEP OPS	1.4	23	0	0	0	4.8	11.2	0	0	0	0	0	0	0	16	0.4
Military	MIL EX	2	37	0	0	0	12.6	0	0	9.6	0	0	0	0.4	0	22.6	0
Military	MIL OPS-PEACE	2.2	55.8	0	0	0	23.2	0	0	0	0	0	0	0	0	23.2	32.8
Military	MIL OPS-WAR	1.6	25.6	0	0	0	24.8	0	0	0	0	0	0	0	0	24.8	0
Training	MIL TRA	23.8	243.6	0	0	0.6	32.2	2.6	0	6.8	15.6	0	2	2.8	0	62.6	345.2
Other	MISC	38.8	1289.6	37.4	0	192	429	86.4	0	134.4	84.8	0	2	185	0	1151	340
Other	MSA	1	47.2	0	0	0	0	0	0	19	13.8	0	0	0	0	32.8	0
Training	OP TRA	253.2	1759.4	17.4	0	89.4	500.4	56.8	0	48.2	77	0	9	71.6	0.4	870.2	1130.8
Other	POLAR OPS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other	PORT SAFE	0.2	32	0	0	0	15.8	0	0	0	0	0	0	0	0	15.8	0
Military	PORT SEC-MIL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other	PORT SEC-OTHER	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other	PUB AFFAIRS	34.8	519.2	2.8	0	6.6	53.4	12.4	0	7.6	30.6	0	0	32.4	0	145.8	354.4
Other	RAD NAV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other	REC BOAT SAFE	0.8	56	0	0	0	33.6	0	0	0	2.6	0	0	0	0	36.2	0
Training	REF TRA	9.4	2170.8	30.8	0	588	304.8	219.4	0	251.8	40.4	0	0	279.4	0	1714.6	1242.4
Training	RESERVE	0.2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Search & Resc.	SAR	147.6	2718.4	199.8	0	23.4	570.8	102	0	39	178	0	15.2	31.6	0	1159.8	3.8
Other	SPECIAL A	2.4	1379.8	0	0	18.8	355.4	0	0	0	0	0	0	15.6	0	389.8	31.2
Other	SPECIAL B	0.6	4.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	TOTALS:	690.4	65163	3209.2	0	1550.8	23608.4	2400.4	0	2733.6	4296.8	0	786.8	1680.4	0.4	40266.8	4703.4

Maint hrs 62617.2 Standby hrs 28679.2 Total 93294.6 2684.45 313.56

Maint days:	
Maint and Repair:	2057.2
Maint Avail:	241.8
Maint Drydock:	192.2
Maint Unsched:	16
Maint Total:	2507.2

Data Summary:	HP	AFHP	TOTAL
Underway Days:	70.6	1891.6	1962.2
Inport Ops Days:	70	144	214
High Red. Hours:	18	94.4	112.4
Maint. Days:	2269.8	240	2509.8
Stdby. Days:	63	47.2	110.2
Total Days:	2491.4	2417.2	4908.6

Total Cutters: 15

CUTTER QUARTERLY EMPLOYMENT - SUMMARY BY RESOURCE

CUTTER
WLB225

	EMPLOYMENT	MISSN	EMPHRS	DD01	DD02	DD05	DD07	DD08	DD09	DD11	DD13	DD14	DD17	GL	HQ	Sum	IN-O	High
Other	A TO N	66	2,034	1,431	0	163	3	0	0	0	0	221	0	0	0	1,818	354	61
Other	BRIDGE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Training	CADET/OC	3	677	67	0	1	0	0	0	0	0	0	0	31	0	98	55	0
Military	COOP-FED	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Military	COOP-LOCAL	1	2	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Military	COOP-STATE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other	DOM ICE	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Drug	ELT DRUGS-AIR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Drug	ELT DRUGS-SURF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fisheries	ELT FISH-DOM	14	555	283	0	1	0	0	0	0	0	144	0	0	0	428	27	6
Fisheries	ELT FISH-FOR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Immigration	ELT MIGRANT	0	274	0	0	0	0	0	0	0	0	204	0	0	0	204	5	67
Other	ELT OTHER	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other	ELT SANCTS	1	4	2	0	1	0	0	0	0	0	0	0	0	0	3	0	0
Military	INTNATL AFFAIRS	2	196	12	0	2	0	0	0	0	0	0	0	135	0	148	198	0
Other	MARINE INSP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other	MEP ENFORCE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other	MEP MARPOL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other	MEP OPS	7	24	23	0	0	0	0	0	0	0	0	0	0	0	23	67	1
Military	MIL EX	1	32	32	0	0	0	0	0	0	0	0	0	0	0	32	3	0
Military	MIL OPS-PEACE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Military	MIL OPS-WAR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Training	MIL TRA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other	MISC	34	610	110	0	91	41	0	150	63	0	62	0	39	0	558	248	47
Other	MSA	6	138	44	0	0	0	0	1	0	0	60	0	0	0	105	22	8
Training	OP TRA	85	919	189	0	37	3	0	79	0	0	282	0	38	0	629	701	106
Other	POLAR OPS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other	PORT SAFE	1	3	3	0	0	0	0	0	0	0	0	0	0	0	3	0	0
Military	PORT SEC-MIL	1	6	6	0	0	0	0	0	0	0	0	0	0	0	6	1	0
Other	PORT SEC-OTHER	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other	PUB AFFAIRS	29	232	53	0	22	3	0	2	0	0	1	0	0	0	80	217	0
Other	RAD NAV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other	REC BOAT SAFE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Training	REF TRA	5	159	73	0	4	38	0	0	0	0	0	0	0	0	115	46	54
Training	RESERVE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Search & Resc.	SAR	5	42	32	0	1	0	0	0	0	0	1	0	0	0	34	0	54
Other	SPECIAL A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other	SPECIAL B	1	4	3	0	0	0	0	0	0	0	0	0	0	0	3	0	0
	TOTALS:	260	5,919	2,364	0	324	87	0	232	63	0	976	0	243	0	4,289	1,943	404
		Maint hrs	7,989		Standby hrs		6,706		Total	21,366						1,379	625	

Maint days:	
Maint and Repair:	221.8667
Maint Avail:	73.06667
Maint Drydock:	15.46667
Maint Unsched:	7.733333
Maint Total:	318.1333

Data Summary:	HP	AFHP	TOTAL
Underway Days:	56.2667	240.267	296.533
Inport Ops Days:	89.0667	48.8	137.867
High Red. Hours:	4.26667	5.33333	9.6
Maint. Days:	236.8	81.3333	318.133
Stdby. Days:	114.933	11.4667	126.4
Total Days:	501.333	387.2	888.533

Total Cutters: 3

CUTTER QUARTERLY EMPLOYMENT - SUMMARY BY RESOURCE

CUTTER
WMEC270

	EMPLOYMENT	MISSN	EMPHRS	DD01	DD02	DD05	DD07	DD08	DD09	DD11	DD13	DD14	DD17	GL	HQ	Sum
Other	A TO N	1.8	27.8	7.2	0	13.6	0.8	0	0	0	0	0	0.8	0	0	22.4
Other	BRIDGE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Training	CADET/OC	7.8	4584.4	14.2	0	23.8	67.6	0	16.6	0	0	0	0	0	0	122.2
Military	COOP-FED	2.8	84	11.4	0	7.4	18.2	0	0	0	0	0	0	0	0	37
Military	COOP-LOCAL	0.4	1.2	0	0	0	0	0	0	0	0	0	0	0	0	0
Military	COOP-STATE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other	DOM ICE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Drug	ELT DRUGS-AIR	1.2	140.6	0.2	0	0	3.6	0	0	0	0	0	0	0	0	3.8
Drug	ELT DRUGS-SURF	71.2	21819.4	468	0	1434.4	11656.2	150.4	0	0	0	0	0	636.4	0	14345.4
Fisheries	ELT FISH-DOM	56	9102	6010.2	0	408	157.8	477	0	23	0	0	95.2	150.2	0	7321.4
Fisheries	ELT FISH-FOR	1.8	573.2	66.8	0	0	56.8	1	0	0	0	0	0	0	0	124.6
Immigration	ELT MIGRANT	78.4	17419.8	485.2	0	555	11312.8	15.4	0	0	0	0	0	17.2	0	12385.6
Other	ELT OTHER	46.4	2242	232.4	0	354.2	278	151.4	0	0	0	0	0	0	0	1016
Other	ELT SANCTS	3	38.6	5.4	0	0.4	13.6	0.2	0	0	0	0	0	0	0	19.6
Military	INTNATL AFFAIRS	41	2646.4	0.4	0	25.2	638.2	47.6	0	0	0	0	0	688.4	0	1399.8
Other	MARINE INSP	0.6	2.8	2.4	0	0	0	0	0	0	0	0	0	0	0	2.4
Other	MEP ENFORCE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other	MEP MARPOL	1	1.2	0.4	0	0	0	0	0	0	0	0	0	0	0	0.4
Other	MEP OPS	2.4	67.8	35.6	0	0	3.6	24.2	0	0	0	0	0	0	0	63.4
Military	MIL EX	7.4	499.4	98.4	0	222	29.6	0.4	0	0	0	0	0	0	0	350.4
Military	MIL OPS-PEACE	8.8	218	5	0	2	59.8	0	0	0	0	0	0	7	0	73.8
Military	MIL OPS-WAR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Training	MIL TRA	34.4	406.6	11.2	0	22.6	172.6	1.4	0	0	0	0	0	23.2	0	231
Other	MISC	41.2	618.4	65.6	0	154.8	192.2	0	0	0	0	0	0.4	7.4	0	420.4
Other	MSA	2.8	81.6	21.4	0	0	7.2	0	0	0	0	0	0	0	0	28.6
Training	OP TRA	395.2	2552.6	149.4	0	208	572.4	14.2	0	0	0	0	0.6	81.4	0	1026
Other	POLAR OPS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other	PORT SAFE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Military	PORT SEC-MIL	0.2	1	0	0	0	[illegible]	0	0	0	0	0	0	0	0	1
Other	PORT SEC-OTHER	0.2	17.6	0	0	0	17.6	0	0	0	0	0	0	0	0	17.6
Other	PUB AFFAIRS	30.6	489.4	56.4	0	38	15.2	9	29.8	0	0	0	0	0	0	148.4
Other	RAD NAV	0.2	0.8	0	0	0.8	0	0	0	0	0	0	0	0	0	0.8
Other	REC BOAT SAFE	0.4	0.8	0	0	0.2	0	0	0	0	0	0	0	0	0	0.2
Training	REF TRA	19.8	3086.2	56.2	0	244.8	2079.2	0	0	0	0	0	0	90.4	0	2470.6
Training	RESERVE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Search & Resc.	SAR	139	2121.4	451.8	0	89	815.8	39.6	0.6	0	0	0	2.4	41.8	0	1441
Other	SPECIAL A	5.8	1158.8	16.6	0	10.8	23.8	0	0	0	0	0	0	0	0	51.2
Other	SPECIAL B	5.4	256.8	0	0	0	0	0	0	0	0	0	0	0.2	0	0.2
	TOTALS:	1007.2	70260.6	8271.8	0	3815	28193.6	931.8	47	23	0	0	99.4	1743.6	0	43125.2
		Maint hrs	56971.6		Standby hrs		3786.4		Total	113942.4						3317.323

Maint days:		Data Summary:	HP	AFHP	TOTAL
Maint and Repair:	1894.2	Underway Days:	63.6	1969	2032.6
Maint Avail:	189	Inport Ops Days:	27.2	125.4	152.6
Maint Drydock:	220.6	High Red. Hours:	20.2	110.2	130.4
Maint Unsched:	17.8	Maint. Days:	2241	80.6	2321.6
Maint Total:	2321.6	Stdby. Days:	82.6	27.8	110.4
		Total Days:	2434.6	2313	4747.6

Total Cutters: 13

CUTTER QUARTERLY EMPLOYMENT - SUMMARY BY RESOURCE

CUTTER
WHEC 378

	EMPLOYMENT	MISSN	EMPHRS	DD01	DD02	DD05	DD07	DD08	DD09	DD11	DD13	DD14	DD17	GL	HQ	Sum
Other	A TO N	2.2	34.8	0	0	0	0	0	0	2.2	0	1.6	5	0	0	8.8
Other	BRIDGE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Training	CADET/OC	16	12004	2.2	0	1.6	37.6	0	0	17.6	9.2	2	98.6	234.6	0	403.4
Military	COOP-FED	2	394.6	0	0	0	25.2	0	0	0.4	0	0	4.4	0	0	30
Military	COOP-LOCAL	1.6	35.6	0	0	0	0	0	0	0	0	0	0.4	0	0	0.4
Military	COOP-STATE	0.8	3.2	0	0	0	0	0	0	0	0	0	1.4	0	0	1.4
Other	DOM ICE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Drug	ELT DRUGS-AIR	4.6	2664.2	11.8	0	18.6	343	0	0	63.2	0	0	0	309.8	0	746.4
Drug	ELT DRUGS-SURF	17.4	8678.4	31	0	41.8	884.8	0	0	2117	143.2	125.4	9.8	1747.2	0	5100.2
Fisheries	ELT FISH-DOM	30.6	17742.4	0	0	0	0	0	0	678	943.2	2299.6	11595.6	321.4	0	15837.8
Fisheries	ELT FISH-FOR	5.4	2526.8	0	0	0	0	0	0	86	30.8	322.8	871	241	0	1551.6
Immigration	ELT MIGRANT	9.6	5512.6	189	0	54.8	2373.2	0	0	740.6	14.8	65.6	131.8	0	0	3569.8
Other	ELT OTHER	5	1124.6	0	0	0	29.4	0	0	25.4	44	505.4	225.4	210.8	0	1040.4
Other	ELT SANCTS	8	141.4	0	0	0	0	0	0	7.4	1.2	3.2	36.8	0	0	48.6
Military	INTNATL AFFAIRS	11.6	2734.8	8.4	0	3.8	2.6	0	0	26.6	0	142.4	21	910.8	0	1115.6
Other	MARINE INSP	0.4	31.8	0	0	0	0	0	0	0	0	0	1	0	0	1
Other	MEP ENFORCE	0.4	9.6	0	0	0	0	0	0	0	0	0	9.6	0	0	9.6
Other	MEP MARPOL	0.2	2.2	0	0	0	0	0	0	0	0	0	2.2	0	0	2.2
Other	MEP OPS	1.6	63.6	0	0	0	0	0	0	0.4	4	0	41	0	0	45.4
Military	MIL EX	8.6	1338.6	0.2	0	0	0	0	0	495.4	47.6	414.4	34.6	195.2	0	1187.4
Military	MIL OPS-PEACE	9.2	647.8	1	0	16.8	146.6	0	0	68	0	0.8	16.2	265.8	0	515.2
Military	MIL OPS-WAR	4	550.6	0	0	0	95	0	0	0	0	0	0	183.8	0	278.8
Training	MIL TRA	50	405.4	0	0	1.2	24.6	0	0	165	17	21.8	20.6	6.8	0	257
Other	MISC	53.6	1736	11	0	9.4	8.4	0	0	244.4	78.6	41.4	84	11	0	488.2
Other	MSA	1.6	40	0	0	0	0	0	0	0	0	0	32.4	1.8	0	34.2
Training	OP TRA	408.4	3429.6	37	0	4.8	68.6	0	0	331.8	139.8	198.2	306.2	96.6	0	1183
Other	POLAR OPS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other	PORT SAFE	0.8	12.8	0.4	0	0	0	0	0	0	12.4	0	0	0	0	12.8
Military	PORT SEC-MIL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other	PORT SEC-OTHER	0.8	3.2	0	0	0	2.4	0	0	0	0.8	0	0	0	0	3.2
Other	PUB AFFAIRS	51.4	1170	6.2	0	0	45.2	0	0	105.2	51	27.2	35.6	0.8	0	271.2
Other	RAD NAV	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Other	REC BOAT SAFE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Training	REF TRA	14.8	4141	15.6	0	30.8	361.6	0	0	1595.2	153	661.2	0	356.6	0	3174
Training	RESERVE	2.6	78	0	0	1.6	2.4	0	0	0	0	0	0	4	0	8
Search & Resc.	SAR	150.8	2451.2	0	0	7.4	105.2	0	0	77.6	20.8	161	634.4	21.4	0	1027.8
Other	SPECIAL A	0.6	301.4	0	0	0	0	0	0	0	0	0	0	0	0	0
Other	SPECIAL B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	TOTALS:	874.6	70010.2	313.8	0	192.6	4555.8	0	0	6847.4	1711.4	4994	14219	5119.4	0	37953.4

Maint hrs 51450 Standby hrs 6242.4 Total 105177.4 3162.783

Maint days:	0
Maint and Repair:	1598.8
Maint Avail:	299
Maint Drydock:	108.8
Maint Unsched:	59
Maint Total:	2065.6

Data Summary:	HP	AFHP	TOTAL
Underway Days:	82.2	1724.8	1807
Inport Ops Days:	93.2	184.8	278
High Red. Hours:	11.8	57	68.8
Maint. Days:	1975	90.6	2065.6
Stdby. Days:	109.4	53.6	163
Total Days:	2271.6	2110.8	4382.4

Total Cutters: 12

APPENDIX G. CLASS FUEL CONSUMPTION SOURCE DATA SUMMARY

Fuel Consumption Information Provided by LCDR Mike Walz

Gallons Per Year

WMEC 210'	FY97	FY98	1/2 FY 99
ACTIVE	233,721	238,619	59,722
ALERT	157,076	199,418	77,744
CONFIDENCE	229,036	326,272	139,858
COURAGEOUS	228,787	312,245	97,159
DAUNTLESS	304,637	332,758	153,330
DECISIVE	-	-	37,729
DEPENDABLE	-	264,623	166,365
DILIGENCE	268,195	282,615	127,816
DURABLE	294,975	268,495	158,046
RELIANCE	255,679	242,396	160,214
RESOLUTE	217,836	267,428	133,710
STEADFAST	120,865	126,932	92,785
VALIANT	322,859	281,461	120,015
VENTUROUS	265,396	268,388	66,055
VIGILANT	325,344	403,904	184,727
VIGOROUS	187,782	227,982	200,259
Yearly Average	243,728	269,569	246,942*
3-Year Average	**253,413**		

* - Average of 1/2 of FY99 doubled

WMEC 270'	FY97	FY98	1/2 FY 99
BEAR	332,746	435,653	110,563
CAMPBELL	354,885	401,889	176,821
ESCANABA	371,593	317,805	163,868
FORWARD	550,827	407,890	197,463
HARRIET LANE	448,512	459,016	133,293
LEGARE	476,555	394,110	171,833
MOHAWK	445,113	414,465	160,170
NORTHLAND	483,975	403,359	148,102
SENECA	410,448	372,395	-
SPENCER	362,082	356,080	100,785
TAHOMA	331,680	365,261	201,431
TAMPA	506,110	358,931	180,230
THETIS	321,359	317,841	156,851
Yearly Average	415,068	384,977	316,902*
3-Year Average	372,315		

WHEC 378'	FY97	FY98	1/2 FY 99
BOUTWELL	671,754	739,247	435,939
CHASE	1,131,327	2,000,872	528,653
DALLAS	899,875	1,144,096	307,465
GALLATIN	773,565	1,296,287	372,014
HAMILTON	810,117	1,079,545	384,672
JARVIS	1,024,800	849,099	701,422
MELLON	991,187	708,183	353,499
MIDGETT	901,032	694,618	255,133
MORGENTHAU	761,703	573,237	361,710
MUNRO	583,386	839,587	485,272
RUSH	881,325	775,362	370,887
SHERMAN	701,066	621,676	337,749
Yearly Average	844,261	943,484	815,736*
3-Year Average	**867,827**		

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APPENDIX H. CLASS ANNUAL FUEL CONSUMPTION ESTIMATION

Table H-1. WMEC 210' Class annual fuel consumption.

Mission	Machinery Alignment	Speed Profile Hours at Speeds	Fuel Rate [GPH]	Fuel Consumed Per Mission [Gallons]
Drug	Single Engine	380 (50%) @ 8 kts.	44.8	83,700
	Single Engine	114 (15%) @ 10 kts.	71.4	
	Two Engines	114 (15%) @ 14 kts.	128	
	Two Engines	152 (20%) @ 17 kts.	289	
Fisheries	Single Engine	300 (50%) @ 8 kts.	44.8	40,000
	Single Engine	210 (35%) @ 10 kts.	71.4	
	Two Engines	90 (15%) @ 14 kts.	128	
	Two Engines	0 @ 17 kts.	289	
Immigration	Single Engine	433 (50%) @ 8 kts.	44.8	86,000
	Single Engine	173 (20%) @ 10 kts.	71.4	
	Two Engines	130 (15%) @ 14 kts.	128	
	Two Engines	130 (15%) @ 17 kts.	289	
Military	Single Engine	38 (60%) @ 8 kts.	44.8	6,640
	Single Engine	0 @ 10 kts.	71.4	
	Two Engines	16 (25%) @ 14 kts.	128	
	Two Engines	10 (15%) @ 17 kts.	289	
Search and Rescue	Single Engine	39 (50%) @ 8 kts.	44.8	13,000
	Single Engine	0 @ 10 kts.	71.4	
	Two Engines	0 @ 14 kts.	128	
	Two Engines	39 (50%) @ 17 kts.	289	
Training	Single Engine	71 (40%) @ 8 kts.	44.8	12,900
	Single Engine	71 (40%) @ 10 kts.	71.4	
	Two Engines	36 (20%) @ 14 kts.	128	
	Two Engines	0 @ 17 kts.	289	
Other	Single Engine	70 (50%) @ 8 kts.	44.8	8,130
	Single Engine	70 (50%) @ 10 kts.	71.4	
	Two Engines	0 @ 14 kts.	128	
	Two Engines	0 @ 17 kts.	289	
			Total Underway	250,400

Table H-2. WLB 225' Class annual fuel consumption.

Mission	Machinery Alignment	Speed Profile Hours at Speeds	Fuel Rate [GPH]	Fuel Consumed Per Mission [Gallons]
Drug	Maneuvering Mode	0 @ 8 kts.	84.0	0
	Single Engine	0 @ 10 kts.	53.1	
	Two Engines	0 @ 14 kts.	112	
	Two Engines	0 @ 17 kts.	264	
Fisheries	Maneuvering Mode	69 (50%) @ 8 kts.	84.0	13,500
	Single Engine	0 @ 10 kts.	53.1	
	Two Engines	69 (50%) @ 14 kts.	112	
	Two Engines	0 @ 17 kts.	264	
Immigration	Maneuvering Mode	0 @ 8 kts.	84.0	7,420
	Single Engine	33 (50%) @ 10 kts.	53.1	
	Two Engines	20 (30%) @ 14 kts.	112	
	Two Engines	13 (20%) @ 17 kts.	264	
Military	Maneuvering Mode	0 @ 8 kts.	84.0	4,600
	Single Engine	36 (60%) @ 10 kts.	53.1	
	Two Engines	24 (40%) @ 14 kts.	112	
	Two Engines	0 @ 17 kts.	264	
Search and Rescue	Maneuvering Mode	6 (50%) @ 8 kts.	84.0	2,090
	Single Engine	0 @ 10 kts.	53.1	
	Two Engines	0 @ 14 kts.	112	
	Two Engines	6 (50%) @ 17 kts.	264	
Training	Maneuvering Mode	0 @ 8 kts.	84.0	20,700
	Single Engine	162 (60%) @ 10 kts.	53.1	
	Two Engines	108 (40%) @ 14 kts.	112	
	Two Engines	0 @ 17 kts.	264	
Other	Maneuvering Mode	417 (50%) @ 8 kts.	84.0	81,700
	Single Engine	0 @ 10 kts.	53.1	
	Two Engines	417 (50%) @ 14 kts.	112	
	Two Engines	0 @ 17 kts.	264	
			Total Underway	130,000

Table H-3. WMEC 270' Class annual fuel consumption.

Mission	Machinery Alignment	Speed Profile Hours at Speeds	Fuel Rate [GPH]	Fuel Consumed Per Mission [Gallons]
Drug	Single Engine	552 (50%) @ 8 kts.	52.8	118,000
	Single Engine	166 (15%) @ 10 kts.	69.7	
	Two Engines	166 (15%) @ 14 kts.	143	
	Two Engines	221 (20%) @ 17 kts.	243	
Fisheries	Single Engine	286 (50%) @ 8 kts.	52.8	47,700
	Single Engine	115 (20%) @ 10 kts.	69.7	
	Two Engines	172 (30%) @ 14 kts.	143	
	Two Engines	0 @ 17 kts.	243	
Immigration	Single Engine	0 @ 8 kts.	52.8	120,000
	Single Engine	476 (50%) @ 10 kts.	69.7	
	Two Engines	286 (30%) @ 14 kts.	143	
	Two Engines	191 (20%) @ 17 kts.	243	
Military	Single Engine	0 @ 8 kts.	52.8	15,300
	Single Engine	72 (50%) @ 10 kts.	69.7	
	Two Engines	72 (50%) @ 14 kts.	143	
	Two Engines	0 @ 17 kts.	243	
Search and Rescue	Single Engine	0 @ 8 kts.	52.8	17,200
	Single Engine	55 (50%) @ 10 kts.	69.7	
	Two Engines	0 @ 14 kts.	143	
	Two Engines	55 (50%) @ 17 kts.	243	
Training	Single Engine	0 @ 8 kts.	52.8	31,500
	Single Engine	148 (50%) @ 10 kts.	69.7	
	Two Engines	148 (50%) @ 14 kts.	143	
	Two Engines	0 @ 17 kts.	243	
Other	Single Engine	69 (50%) @ 8 kts.	52.8	13,500
	Single Engine	0 @ 10 kts.	69.7	
	Two Engines	69 (50%) @ 14 kts.	143	
	Two Engines	0 @ 17 kts.	243	
			Total Underway	363,200

Table H-4. WHEC 378' Class annual fuel consumption.

Mission	Machinery Alignment	Speed Profile Hours at Speeds	Fuel Rate [GPH]	Fuel Consumed Per Mission [Gallons]
Drug	Single Diesel Engine	869 (60%) @ 8 kts.	126	379,000
	Two Diesel Engines	362 (25%) @ 10 kts.	181	
	Single Gas Turbine	72 (5%) @ 14 kts.	602	
	Single Gas Turbine	72 (5%) @ 17 kts.	814	
	Two Gas Turbines	36 (2.5%) @ 20 kts.	1,300	
	Two Gas Turbines	36 (2.5%) @ 22 kts.	1,530	
Fisheries	Single Diesel Engine	244 (50%) @ 8 kts.	126	137,000
	Two Diesel Engines	122 (25%) @ 10 kts.	181	
	Single Gas Turbine	73 (15%) @ 14 kts.	602	
	Single Gas Turbine	49 (10%) @ 17 kts.	814	
	Two Gas Turbines	0 @ 20 kts.	1,300	
	Two Gas Turbines	0 @ 22 kts.	1,530	
Immigration	Single Diesel Engine	251 (60%) @ 8 kts.	126	103,000
	Two Diesel Engines	84 (20%) @ 10 kts.	181	
	Single Gas Turbine	52 (12.5%) @ 14 kts.	602	
	Single Gas Turbine	31 (7.5%) @ 17 kts.	814	
	Two Gas Turbines	0 @ 20 kts.	1,300	
	Two Gas Turbines	0 @ 22 kts.	1,530	
Military	Single Diesel Engine	178 (60%) @ 8 kts.	126	75,600
	Two Diesel Engines	59 (20%) @ 10 kts.	181	
	Single Gas Turbine	30 (10%) @ 14 kts.	602	
	Single Gas Turbine	30 (10%) @ 17 kts.	814	
	Two Gas Turbines	0 @ 20 kts.	1,300	
	Two Gas Turbines	0 @ 22 kts.	1,530	
Search and Rescue	Single Diesel Engine	143 (55%) @ 8 kts.	126	97,600
	Two Diesel Engines	33 (12.5%) @ 10 kts.	181	
	Single Gas Turbine	39 (15%) @ 14 kts.	602	
	Single Gas Turbine	26 (10%) @ 17 kts.	814	
	Two Gas Turbines	7 (2.5%) @ 20 kts.	1,300	
	Two Gas Turbines	13 (5%) @ 22 kts.	1,530	
Training	Single Diesel Engine	66 (40%) @ 8 kts.	126	40,100
	Two Diesel Engines	66 (40%) @ 10 kts.	181	
	Single Gas Turbine	33 (20%) @ 14 kts.	602	
	Single Gas Turbine	0 @ 17 kts.	814	
	Two Gas Turbines	0 @ 20 kts.	1,300	
	Two Gas Turbines	0 @ 22 kts.	1,530	
Other	Single Diesel Engine	43 (50%) @ 8 kts.	126	21,900
	Two Diesel Engines	21 (25%) @ 10 kts.	181	
	Single Gas Turbine	21 (25%) @ 14 kts.	602	
	Single Gas Turbine	0 @ 17 kts.	814	
	Two Gas Turbines	0 @ 20 kts.	1,300	
	Two Gas Turbines	0 @ 22 kts.	1,530	
			Total Underway	854,200